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Cable Modeling Technique in Virtual Assembly for Satellite System

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Abstract-**At present, physical verification of cable assemblies is mainly through simulation assembly in actual project. However, it leads to problems of a long period of production design and high cost. Virtual assembly technology and the development of related technologies provides a new idea for solving problems in cable assembly wiring, and provides a new platform for integrated wiring system. The non-uniform cubic B-spline curve is used to interpolate key path points considering process demand. To reduce singular points in the interpolation curve generated with methods proposed, smoothing treatment towards cable centre line is carried out after calculation of cable curve. These technologies are important parts to design a comprehensive wiring automation software analysis system combined with the computer technology become necessary.**

Keywords-Virtual assembly, Cable assembly, Non-uniform cubic B-spline curve, Smoothing treatment

I. INTRODUCTION

Cable, widely used in electromechanic products such as weapons and equipment, aircraft, automobile and computer is indispensable part of electromechanical system. It is the important component in transmission of current and signals. Cable assemblies wiring has a complicated process and is big difference to the quality of mechanical and electrical products. Cable wiring quality and assembly reliability directly affects product performance and reliability. At present, physical verification of cable assemblies is mainly through simulation assembly in actual project. However, it leads to problems of a long period of production design and high cost.

The current cable assembly in complex products mainly depends on hand sampling in construction site. Non-standard assembly process, poor tolerance and low reliability between electrical connectors have become important factors influencing assembly quality of mechanical and electronic products. At present, the development of mechanical and electronic products in cable is usually divided into the following four processes. The first step is electrical diagram design. The second, design cable according to electrical logic diagram and form wiring harness. The third, wiring scheme and assembly process scheme are determined by repeatedly changing outfits of cables in product prototype. And the last one is cable installation. At this stage, assembly workers assemble cable according to cable assembly drawings in process card. With miniaturization, lightweight, high precision process of complex equipment of aircraft and light, machine, electricity integration development, the irrationality of cable path planning and non-standard assembly process have become one of the important reasons influencing product assembly quality.

At present, many commercial software such as Pro/E, CATIA, provides the cable 3D modeling function modules. However, modeling operating modes provided by these modules are not intuitive and they cannot directly provided cable assemblies wiring interference detection. These will seriously hinder the wide application in the enterprise.

Virtual assembly technology and the development of related technologies provides a new idea for solving problems in cable assembly wiring, and provides a new platform for integrated wiring system. To design a comprehensive wiring automation software analysis system combined with the computer technology becomes necessary.

In research, a number of researchers have long devoted themselves to virtual assembly of cable[1-5]. Cable modeling technique in virtual assembly for satellite system is introduced in this paper.

II. GENERATION OF CABLE CENTRE LINE

To complete the virtal cable assembly in satellite system, the primary task is to find an adaptive method in reprsenting the cable with the effective mathematical model. Choosing appropriate math function to describe cable centre line is one of key problems in establishing cable mathematical model. In this paper, the non-uniform cubic B-spline curve is choosen as the expression builder in cable generation for making full use of its advantage in curve expression. Each cable is generated by a series of key path points considering process demand. We suppose the key path points $\{\boldsymbol{p}_0, \boldsymbol{p}_1, \cdots, \boldsymbol{p}_n\}$. The non-uniform cubic B-spline curve $\boldsymbol{p}(u)$ through the set of key path points is calculated, with a result $\boldsymbol{p}_i \in \boldsymbol{p}(u)(i = 0,1,\cdots,n)$.

At the first stage, the knot vector of $\boldsymbol{p}(u)$ is calculated using a method of standard-chord-length parameterization used widely in Computer-Aided Geometric Design (CAGD). The knot vector calculated is $\boldsymbol{U}$ ($\boldsymbol{U} = [u_0, u_1, \cdots, u_{n+6}]$), in which $[u_3, u_{n+3}] \in [0,1]$, $u_0 = u_1 = u_2 = u_3 = 0$ and $u_{n+3} = u_{n+4} = u_{n+5} = u_{n+6} = 1$.

The internal knot vector of the non-uniform cubic B-spline curve $\boldsymbol{p}(u)$ is calculated with Hartley—Judd method as follows in which the parameter *k* equals to three.

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$$u_i - u_{i-1} = \frac{\sum\limits_{j=i-k}^{i-1} l_j}{\sum\limits_{s=k+1}^{n+1} l_j \sum\limits_{j=s-k}^{s-1} l_j}, \quad i = k+1, k+2, \cdots, n+1 \tag{1}$$

where $l_j = \left\| \boldsymbol{d}_j - \boldsymbol{d}_{j-1} \right\|$

The node values finally calculated are as follows.

$$u_k = 0$$

$$u_i = \sum (u_j - u_{j-1}), \quad j = k+1, k+2, \cdots, n \tag{2}$$

$$u_{n+1} = 1$$

The control points for $\boldsymbol{p}(u)$, $\boldsymbol{d}_j\,(j = 0,1,\cdots,m)$, where m is equal to $n+2$, can be achieved as follows[6].

$$\begin{bmatrix} a_1 & b_1 & c_1 & & \\ a_2 & b_2 & c_2 & & \\ \ddots & \ddots & \ddots & & \\ & & a_{m-2} & b_{m-2} & c_{m-2} \\ & & a_{m-1} & b_{m-1} & c_{m-1} \end{bmatrix} \begin{bmatrix} \boldsymbol{d}_1 \\ \boldsymbol{d}_2 \\ \vdots \\ \boldsymbol{d}_{m-2} \\ \boldsymbol{d}_{m-1} \end{bmatrix} = \begin{bmatrix} \boldsymbol{e}_1 \\ \boldsymbol{e}_2 \\ \vdots \\ \boldsymbol{e}_{m-2} \\ \boldsymbol{e}_{m-1} \end{bmatrix} \tag{3}$$

where

$$\begin{cases} a_i = \dfrac{(\Delta_{i+2})^2}{\Delta_i + \Delta_{i+1} + \Delta_{i+2}} \\ b_i = \dfrac{\Delta_{i+2}(\Delta_i + \Delta_{i+1})}{\Delta_i + \Delta_{i+1} + \Delta_{i+2}} + \dfrac{\Delta_{i+1}(\Delta_{i+2} + \Delta_{i+3})}{\Delta_{i+1} + \Delta_{i+2} + \Delta_{i+3}}, & i = 2,3,\cdots,m-2 \\ c_i = \dfrac{(\Delta_{i+1})^2}{\Delta_{i+1} + \Delta_{i+2} + \Delta_{i+3}} \\ \boldsymbol{e}_i = (\Delta_{i+1} + \Delta_{i+2})\boldsymbol{p}_{i-1} \end{cases}$$

and $\Delta_i = u_{i+1} - u_i$.

$a_1, b_1, c_1, \boldsymbol{e}_1$ and $a_{m-1}, b_{m-1}, c_{m-1}, \boldsymbol{e}_{m-1}$ can be given out consulting the Ref.[11]. $\boldsymbol{d}_1, \boldsymbol{d}_2, \cdots, \boldsymbol{d}_{m-1}$ can be calculated by Eq.(3). $\boldsymbol{d}_j\,(j=0,1,\cdots,m)$ will be confirmed after a supposition $\boldsymbol{d}_0 = \boldsymbol{p}_0$ and $\boldsymbol{d}_m = \boldsymbol{p}_n$. With knot vector $\boldsymbol{U}$ and control points $\boldsymbol{d}_j\,(j = 0,1,\cdots,m)$, the non-uniform rational B-spline interpolation curve $\boldsymbol{p}(u)$ is confirmed.

III. SMOOTHING TREATMENT OF CABLE CENTRE LINE

The interpolation curve generated with methods introduced in section 1 may have singular points, which can not meet curvatures requirements of the cable. So, smoothing treatment towards cable centre line will be carried out after calculation of cable curve.

There are two ways to smooth the curve interpolating the cable. The comprehensive wiring automation software for cable assembly wiring firstly judges the fairness of curve, then revises the bad points in the curve, and finally carrys out related operation towards the calculated curve in section 2. For curves of big deflection, energy methods are adopted and selected-point method is used for curves of small deflection.

The basic principle of selected-point method according to the standards for local light, checking points time after time, is gradually finding out points not accord with the light of the conditions of the type of point (what say normally namely "bad point"), which in turn to bad point is revised. This process is carried out as a reciprocating modification operation, until the curve accords with the light of the criterion conditions.

We suppose the given path points $\{\mathbf{P}_i \,|\, i = 1,2,\cdots,n\}$, and $\mathbf{p}(t)$ is a curve through the set of key path points. We project $\mathbf{P}_i\,(i = 1,2,\cdots,n)$ and $\mathbf{p}(t)$ to the plane *XOY* and the plane *ZOX* respectively. The fairing process will be carried out towards project curves.

Supposing the relative curvature of $\mathbf{p}(t)$ at $\{\mathbf{P}_i \,|\, i = 1,2,\cdots,n\}$ k_i , we find out points meet the following conditions.

$$\begin{cases} k_{i-1}.k_i < 0 \\ k_i.k_{i+1} < 0 \end{cases} \tag{4}$$

There can be several points meet the conditions and they may be extreme points. We suppose $f_{i+}^{(3)}$ and $f_{i-}^{(3)}$ are the third derivatives of this curve at the i*th* path point.

$$N_i = \max \left| f_{i+}^{(3)} - f_{i-}^{(3)} \right| \tag{5}$$

Calculating all N values of the bad points, the point which corresponds the bigest *N* value is the one to be revise up at the front.

Supposing the worst point (x_i, y_i) , this bad point will be eliminated and the remaining type point will be used to generate a new spline interpolation function structure. Using x_i and the function generated, the value Y_i will be calculated out. The distance between Y_i and y_i will be calculated out as follows.

$$L_i = \left\| y_i - Y_i \right\| \tag{6}$$

The value y_i will be replace with Y_i if the condition followed established. Inversely, y_i will be replace with

$$y_i + \varepsilon \frac{L_i}{\left\| L_i \right\|} \tag{7}$$

The energy methods are discussed in detail in this paper. We suppose the key path points $\{\boldsymbol{p}_0, \boldsymbol{p}_1, \cdots, \boldsymbol{p}_n\}$. The non-uniform cubic B-spline curve through the set of key path points is $\boldsymbol{p}(u)$. The path points after smoothing treatment is $\{\mathbf{q}_i \,|i = 1, 2, \cdots, n\}$, and the interpolation curve is $\mathbf{q}(t)$. The curve strain-energy of $\boldsymbol{p}(u)$ applied elastic force is shown by Eq.(8).

$$E = (\frac{\alpha}{2}\int k^2 ds) + (\frac{1}{2}\sum_{i=0}^{n}\beta_i \left\|\mathbf{p}_i + \mathbf{q}_i\right\|^2) \qquad (8)$$

We can find that the curve energy is consisted of two parts: strain energy of the curve and elasticity energy of the curve. Strain energy shows fairing performance of the curve and elasticity energy presents deviate degree of the new curve towards the original curve. And so, coefficient α is called smooth factor, and β approximation factor. We suppose curve $\mathbf{p}(t)$ expressed by $\mathbf{p}(t) = \sum_{j=0}^{n+2} \mathbf{d}^o{}_j N^o{}_{j,3}(t)$, and curve $\mathbf{q}(t)$ by $\mathbf{q}(t) = \sum_{j=0}^{n+2} \mathbf{d}_j N_{j,3}(t)$, in which $\mathbf{d}^o{}_j$ and $\mathbf{d}_j$ are called control points. $N^o{}_{j,3}(t)$ and $N_{j,3}(t)$ are basis functions. There is a linear equation group shown by Eq.(9) with an assumption that $\mathbf{D} = (\mathbf{d}_0, \mathbf{d}_1, \cdots, \mathbf{d}_{n+2})^T$.

$$\mathbf{AD} = \mathbf{C} \qquad (9)$$

In Eq.(5), coefficient matrix $\mathbf{A}$ is square matrix of $n+3$ dimensional. And matrix elements $a_{i,j}$ ($i = 0, 1, \cdots, n+2$; $j = 0, 1, n+2$) is calculated by Eq.(10).

$$a_{i,j} = \alpha\sum_{k=1}^{n}\int_{t_{k+2}}^{t_{k+3}} N''_{i,3}(t)N''_{j,3}(t)dt + \sum_{k=0}^{n}\beta_k N_{i,3}(t_{k+3})N_{j,3}(t_{K+3}) \qquad (10)$$

$\mathbf{C}_i$, in matrix $\mathbf{C} = (\mathbf{C}_0, \mathbf{C}_1, \cdots, \mathbf{C}_{n+2})$, is calculated by Eq.(11).

$$\mathbf{C}_i = \sum_{k=0}^{n}\beta_k \mathbf{p}_k N_{i,3}(t_{k+3}), \qquad i = 0, 1, \cdots, n \qquad (11)$$

Knot values of curve $\mathbf{p}(t)$ is put into the equation $\mathbf{q}(t)$ in turn and data points sequence $\mathbf{q}_i (i = 1, 2, \cdots, n)$ is calculated. Then we calculate maximum values of $L_i = \left\|\mathbf{p}_i - \mathbf{q}_i\right\| (i = 1, 2, \cdots, n)$, and compare them with maximum tolerance ε. If there is a condition $L_i \le \varepsilon$, the curve $\mathbf{q}(t)$ is the satisfied curve. Otherwise, with parameters $\alpha = \alpha/2, \alpha/4, \alpha/8\cdots$, control points $\mathbf{d}_j$ ($j = 0, 1, \cdots, n+2$) is calculated once more till it meet maximum tolerance requirements.

IV. SUMMARIES

Cable modeling technique in virtual assembly for satellite system is introduced in this paper. The non-uniform cubic B-spline curve is used to interpolate key path points considering process demand. To reduce singular points in the interpolation curve generated with methods proposed, smoothing treatment towards cable centre line is carried out after calculation of cable curve. These technologies are important parts to design a comprehensive wiring automation software analysis system combined with the computer technology becomes necessary.

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