Linguistic Operation System for Design of Architectural Form

Yoshitsugu Aoki and Makoto Inage
Tokyo Institute of Technology
Department of Architecture, Faculty of Engineering
2-12-1 Ohokayama, Meguro-ku, Tokyo 152-8552
Japan

ABSTRACT

In a process of architectural design, an architect not only draws by himself/herself but also lets another person modify a design by given a linguistic instruction expressing how the design ought to be. In the case of utilization of CAD systems, it is useful if the system modifies the design according to the linguistic instruction. On the other hand, because of the recent increase of the opportunities of designing a building whose roof has complicated curved surface, it extremely takes labor to change the design. This paper proposes a linguistic operation system that modifies a design according to the linguistic instruction of the modification by the user to support design of a complicated form with curved surface. The proposed system is expected to be integrated with a CAD system. First, the system presents a perspective sketch of a designed form. From the values of the design variables that characterize the form in the system, the system calculates the position of the form in “the association image space.” Second, the designer puts a linguistic instruction i.e., words as like as “let it be more light” to modify the form. The words used for the instruction have the position in the association image space. In the association image space, the system moves the position of the form to a new position that gets to be near the position of the given word. The system calculates the values of the design variables of the form corresponding to the new position. We need a mapping from every vector representing the position of the changed form in the association image space to the corresponding vector representing the values of the design variables. To find the mapping, we construct a neural network system with three levels. Finally, the system presents a perspective sketch of changed form using the calculated values of design variables.

1 INTRODUCTION

In a process of architectural design, an architect not only draws by himself/herself but also let another person modify a design by given a linguistic instruction expressing
how the design ought to be. In the case of utilization of CAD systems, it is useful if the system modifies the design according to the linguistic instruction.

On the other hand, because of the recent increase of the opportunities of designing a building whose roof has complicated curved surface, it extremely takes labor to change the design. This paper proposes a linguistic operation system that modifies a design according to the linguistic instruction of the modification by the user.

2 OUTLINE OF LINGUISTIC OPERATION SYSTEM AND RESEARCH PROCESS

The linguistic operation system for design of architectural form, which we propose in below, is expected to be integrated with a CAD system. First, the system presents a perspective sketch of designed form as usual CAD system. From the values of the design variables that characterize the form in the system, the system calculates the position of the form in “the association image space” that is defined in below. In the association image space, the positions of words have been calculated.

Second, the designer puts a linguistic instruction i.e., words as like as “let it be more light” to modify the form while he sees the sketch. In the association image space, the system moves the position of the form into the new position that gets to be near the position of the given word. The system calculates the values of design variables of the form corresponding to new position. Finally, the system presents a perspective sketch of changed form using the calculated values of design variables.

The above procedure of changing operation is repeated until the result that the designer accepts is gotten.

Figure 1: The curved surfaces defined by the bi-dimensional spline function

In order to achieve the function to make the above operation possible, we must develop the methods;
1) a method to represent the complicated form with less design variables,
2) a method to construct the association image space, in which each form and each word are corresponding to the positions,
3) a method to calculate the values of design variables from the coordinate data of the position in the association image space.
The above three problems are solved in following chapters.

3 PRESENTATION SYSTEM OF CURVED SURFACE

In order to represent the roof of the very complicated curved surface, we use bi-dimensional spline functions. That is, when a designer specifies several points on the curved surface, a bi-dimensional spline function that passes the given points is defined through simple calculation. A bi-dimensional spline function is determined by a set of twenty-five parameters. The curved surface defined by the bi-dimensional spline function is presented in the screen as illustrated as Fig.1. The designer can see the form of the curved surface from every angle with rotating operation.

4 CORRESPONDENCE BETWEEN A FORM AND A WORD

4.1 Word association model

Our first goal is to find a relationship between each form and each word. We suppose each form and each word correspond to the point in the $K$ dimensional space. When we consider $N$ types of forms and $M$ word, each form $F_j$ and each word $W_i$ are expressed by following $K$ dimensional vectors,

$$x_j = (x_{j1}, x_{j2}, ..., x_{jk}), \text{ for } j = 1 \text{ to } N,$$

$$a_i = (a_{i1}, a_{i2}, ..., a_{ik}), \text{ for } i = 1 \text{ to } M,$$

where $x_{jk}$ is a variable to express the nature which is peculiar to a form $F_j$ and $a_{ik}$ is a variable to express the nature which is peculiar to a word $W_i$. This $K$ dimensional space defined above is called “Association Image Space.”

On the other hand, when we see a form of curved surface roof, we get an impression and can tell the impression using words. That is, we associate some words for a presented form. Statistically speaking, for each form $F_j$, we can observe a frequency $p_{ij}$ of association of each word $W_i$.

Then, we introduce a following simple model;

$$p_{ij} = \prod_{k=i}^{K} a_{jk} x_{jk} + e_{ij}, \text{ for } i = 1 \text{ to } M, \text{ for } j = 1 \text{ to } N,$$

where $e_{ij}$ is a random variable expressing error. Furthermore, we suppose the vector,
\( a_{(k)} = (a_{1k}, a_{2k}, \ldots, a_{Mk}) \),

is independence each other. That is, each vector is orthogonal. In the same way, the vector:

\( x_{(k)} = (x_{1k}, x_{2k}, \ldots, x_{Nk}) \),

is independence and orthogonal each other.

Furthermore, without losing generality, it is possible to make a standard such that the length of each vector \( a_{(k)} \) is unit, and let the length of each vector \( x_{(k)} \) be root \( \sqrt{k} \). That is,

\[
a_{(k) \in} a_{(k)} = 1 \text{ for all } k,
\]

\[
x_{(k) \in} x_{(k)} = \sqrt{k} \text{ for all } k.
\]

In general, our model can be expressed by a following matrix notion for a set of \( N \) forms and \( M \) words when we suppose that the dimension of \( k \) is \( K \):

\[
P = AX + E,
\]

where \( P \) is a \( M \times N \) matrix whose \( ij \) element is \( p_{ij} \), \( A \) is a \( M \times K \) matrix whose \( ik \) element is \( a_{ik} \), \( X \) is a \( K \times N \) matrix whose \( jk \) element is \( x_{jk} \) and \( E \) is a \( M \times N \) matrix whose \( ij \) element is \( e_{ij} \).

### 4.2 Estimation method of association word model

When we get a set of data on frequency \( p_{ij} \) of association each word \( W_i \) for each form \( F_j \), we can estimate unknown variables \( x_{jk} \) and \( a_{ik} \) by minimizing square sum of errors \( e_{ij} \).

In order to understand the characteristics of our model intuitonally, we show the estimation procedure in the case that dimension \( K \) is 2. In this case, the model is expressed as follows;

\[
p_{ij} = a_{1i}x_{j1} + a_{2i}x_{j2} + e_{ij}.
\]

Then, each error is written as;

\[
e_{ij} = p_{ij} - a_{1i}x_{j1} - a_{2i}x_{j2}.
\]

To minimize the square sum of errors;

\[
V = \sum_{i=1}^{M} \sum_{j=1}^{N} (e_{ij})^2,
\]

We obtain a set of necessary conditions;

\[
\frac{\partial V}{\partial a_{1i}} = 0 \text{ for } i = 1 \text{ to } M,
\]

\[
\frac{\partial V}{\partial a_{2i}} = 0 \text{ for } i = 1 \text{ to } M,
\]
\[
\frac{\partial V}{\partial x_{j1}} = 0 \text{ for } j = 1 \text{ to } N,
\]
\[
\frac{\partial V}{\partial x_{j2}} = 0 \text{ for } j = 1 \text{ to } N.
\]

The first equation is rewritten as
\[
\sum_{j=1}^{N} (a_{11}(x_{j1})^2 - p_{1j} + a_{12}x_{j1}x_{j2}) = 0,
\]
or,
\[
a_{11}\sum_{j=1}^{N} (x_{j1})^2 - \sum_{j=1}^{N} p_{1j}x_{j1} + a_{12}\sum_{j=1}^{N} x_{j1}x_{j2} = 0.
\]

Since vector \( x(k) \) is orthogonal each other, that is,
\[
\sum_{j=1}^{N} x_{j1}x_{j2} = 0,
\]
the above equation reduces to
\[
a_{11}\sum_{j=1}^{N} (x_{j1})^2 - \sum_{j=1}^{N} p_{1j}x_{j1} = 0.
\]

Since the length of vector \( x(k) \) is root \( \|k\| \), the above equation can be written as follows;
\[
\sum_{j=1}^{N} p_{1j}x_{j1} = a_{11}\|k\|.
\]

In the same way, we can get similar equations for every \( i, k \), as
\[
\sum_{j=1}^{N} p_{ij}x_{j1} = a_{ij}\|k\| \text{ for } i = 1 \text{ to } M,
\]
\[
\sum_{j=1}^{N} p_{ij}x_{j2} = a_{ij}\|k\| \text{ for } i = 1 \text{ to } M.
\]

These equations can be written as follows;
\[
P_x(k) = f_{x(k)}^E a_{(k)} \text{ for } k = 1 \text{ to } 2.
\]

In the similar calculation, we can obtain a following equation;
\[
P_{x(k)} = x_{(k)} \text{ for } k = 1 \text{ to } 2.
\]

From these two equations, we can get a following equation;
\[
PP^\perp a_{(k)} = f_{(k)}^E a_{(k)} \text{ for } k = 1 \text{ to } 2.
\]

This means \( f_{(k)}^E \) is an Eugenie value of the matrix of \( PP^\perp \), and vector \( a_{(k)} \) is an eigen vector corresponding to \( f_{(k)}^E \).

The above argument can be extended to general case of \( K \). Then, we can obtain following equation;
\[
PP^\perp a_{(k)} = f_{(k)}^E a_{(k)} \text{ for } k = 1 \text{ to } K.
\]
\(\mathbf{P}_k = f_k \mathbf{a}_k \) for \( k = 1 \) to \( K \).

By solving the above equations determined with given frequency matrix \( \mathbf{P} \), we can obtain the values of vectors \( \mathbf{x}_i \), \( \mathbf{a}_i \) which express the positions of the form \( F_j \) and the word \( W_i \) in the association image space.

4.3 Estimation of association word model

We prepare thirty-one samples of forms of curved surface roof defined by the bi-dimensional spline function. We choose twenty-eight samples of symmetry types in thirty-one samples because the others are very low frequency of association of words. As the word that is possible to associate with seeing the sample forms, we prepare forty Japanese adjectives as shown as table 1. As a result of estimation, we obtain the values of vectors correspond to twenty-eight forms and forty adjectives. The Fig.2 shows the positions of the forms and words in a plane determined by \( k = 2, \) and 3.

Table 1: forty adjectives

<table>
<thead>
<tr>
<th>static</th>
<th>orderly</th>
<th>polishing</th>
<th>disharmonious</th>
<th>plain</th>
</tr>
</thead>
<tbody>
<tr>
<td>dynamic</td>
<td>flat</td>
<td>boldness</td>
<td>organic</td>
<td>soft</td>
</tr>
<tr>
<td>stable</td>
<td>bright</td>
<td>diversified</td>
<td>inorganic</td>
<td>hard</td>
</tr>
<tr>
<td>open</td>
<td>central</td>
<td>uniform</td>
<td>graceful</td>
<td>floating</td>
</tr>
<tr>
<td>closed</td>
<td>artificial</td>
<td>warm</td>
<td>artistic</td>
<td>windlike</td>
</tr>
<tr>
<td>light</td>
<td>clear</td>
<td>cool</td>
<td>complex</td>
<td>sealike</td>
</tr>
<tr>
<td>heavy</td>
<td>vague</td>
<td>calm</td>
<td>simple</td>
<td>ascending</td>
</tr>
<tr>
<td>disorderly</td>
<td>naive</td>
<td>flighty</td>
<td>sharp</td>
<td>tense</td>
</tr>
</tbody>
</table>

5 RELATIONSHIP BETWEEN ASSOCIATION IMAGE SPACE AND DESIGN VARIABLES

5.1 Neural network system as a mapping to design variables

As mentioned in chapter 3, the form of curved surface is represented by the bi-dimensional spline function using twenty-five parameters. That is, a form is represented by twenty-five design variables. Let these parameters of the form \( F_j \) describe with a vector;
\[
\mathbf{y}_j = (y_{j1}, y_{j2}, \ldots, y_{j25}).
\]

On the other hand, the same form \( F_j \) corresponds to the position in the \( K \) dimensional association image space as mentioned in the previous chapter. That is, the form \( F_j \) is represented by a vector;
\[
\mathbf{x}_j = (x_{j1}, x_{j2}, \ldots, x_{jK}).
\]
In order to operate the change of the form by words, we must calculate the values of design variables of the changed form $F_q$ when the position of the changed form is determined in the association image space. That is, we need a mapping, which is must be able to compute of course, from every vector $x_y$ representing the position of the changed form in the association image space to the corresponding vector $y_q$ representing the values of twenty-five design variables.

To find this mapping, we construct a neural network system with three levels as illustrated as Fig.3. The first level of $K$ neurons is the input level in which $k$-th neuron corresponds to $k$-th element of the vector representing the position in $K$ dimensional association image space. The third level of twenty-five neurons is the output level in which each neuron corresponds to the each element of a vector

Figure 2: Positions of the forms and words in a plane determined by $k = 2$, and $3$
representing design variables. We can obtain the mapping function by learning using a set of vectors $x_j$ and $y_j$ of the sample form. This learning process is done by the back propagation method (BPM).

Figure 3: A neural network system

Figure 4: Result of the neural network

Sample forms

No. 1
No. 2

No. 3
In progress of learning
Repeated 100 times

No. 28

No. 3
Good estimated result
Repeated 100,000 times
5.2 Estimation of parameters of neural network system by BPM

We choose $K = 15$ as the dimension of the association image space in the consideration on effectiveness. Then, the number of neurons in the first level of network is fifteen. The number of neurons in the third level is twenty-five as mentioned above, and one of middle level is chosen as fifteen.

The data for learning are twenty-eight pairs of $x_j$ and $y_j$ of the sample forms. For every sample forms, the learning by BPM is repeated 100,000 times, and we get the good estimated result of the neural network as shown as Fig.4.

6 EXAMPLES OF OPERATION

The Fig.5 shows two example cases;
1) when giving linguistic operation, “making stable”, to the form which doesn't have a stable sense,
2) when giving operation, “making more light”, to the form which rather has a light sense.

Figure 5: Examples of linguistic operation

It seems that as a result of the operation “making stable”, the central part gets into waving up, and for the operation “making light”, the both sides finish warping up.
7 CONCLUSION

We proposed a system that modifies the design according to the linguistic indication of the designer to support the architectural design for the very complicated form with curved surface. This system is a prototype, but the methods, which we find out in the process of construction of the system, are effective for the development of more general type of linguistic operation system for design.

REFERENCES