International Journal of Fuzzy Logic and Intelligent Systems, vol. 2, no. 2, June 2002 pp. 127-132

Fuzzy Displays of a surface Deformation for Virtual World

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Abstract

In this paper, a new method for displaying a surface deformation is proposed using the fuzzy model. In the proposed method, it is enough that only one rule is added to the fuzzy model to display a surface deformation. Furthermore, designer can easily determine which parameters should be used and how much they should be changed in order to alter shapes as they want. The proposed method is, thus, a simple, but effective technique that can also be applied to real time operation. The results of the computer simulation are also given to demonstrate the validity of the proposed algorithm.

Key Words : Fuzzy display, Fuzzy model, Surface deformation, Virtual world

I. Introduction

Recently many studies have been conducted on virtual world and its application since it is superior to other forms of human-computer interaction. Thus, it is necessary to take a close look at graphical displays of the virtual world to provide sufficient realism. Among the various components of graphical displays, this paper is focused on the graphical display of surface deformation. Developing better algorithms for surface deformation displays are important to improve the visual realism of virtual world. In reality, surfaces are usefully deformable, so that a pushed virtual object will change shape in response to the user-applied forces. The visual realism can thus be added by the surface deformation models that are interactive and satisfy the real-time requirement of virtual world. The methods for displaying a surface deformation can be largely classified as vertex-based and spline-based, depending on whether the object surface is represented by polygonal meshes or parametric equations[1]. In the vertex-based method, the deformation of one vertex will impact its neighbors, and therefore the object mesh look-up table needs supplemental information.

Another way of representing virtual objects is through parametric cubic surfaces. These have a local control behavior and the time needed to recomputed the polynomial coefficients is greatly reduced. However, this local deformation technique do not suffice when several objects may need to be deformed simultaneously. Furthermore, most of the existing free form deformation methods are indirect ways[2]. Users can not touch surfaces directly, but some special parameters called control points, weights, and so on. In this method, there are many control points and it is hard to predict what deformation can be obtained after several parameters' change even if they are defined only by control points and knot vectors. Designer have to learn how many kinds of parameters they have and the effect of each parameter; therefore, each time they deform forms, users have difficulties in determining which parameters should used and how far they should be changed in order to alter shapes as they want.

The conventional mathematical model exists but is too difficult to encode, or is too complex to be evaluated fast enough for real time operation, or involved too much memory. In this paper, to overcome above problems, we propose a new method which is a simple, but effective technique, that can also applied to real time operation. The approach selected in this paper is based on the fuzzy model to display the nonlinear model.

This paper is organized as follows. In section II, a basic concept of fuzzy model is explained and a new method for surface deformation displays is suggested by using the merits of the fuzzy model. In the next chapter, it is shown that the proposed method is easy to apply and useful for surface deformation displays by simulation. Finally, conclusion is presented.

II. Fuzzy model for elastic deformation

Fuzzy model has been shown to have the capability of modeling complex nonlinear systems, which means that this fuzzy model can also be applied to displaying a complex surface shapes. One of the outstanding models among them is the model suggested by Takagi and Sugeno in 1985[4]. Therefore, we use Takagi and Sugeno' s fuzzy model in order to display a surface deformation. The method of identifying a fuzzy model is essential to an understanding of how the surface deformation is modeled by fuzzy model. But the identification of a fuzzy model is beyond the scope of this paper and for details, the author advises readers to refer to [4]-[8].

This fuzzy model is a nonlinear system model represented

Manuscript received February 2002 ;
revised May 2002
This work was supported by the research fund of Seoul National University of Technology.

by fuzzy rules of the type :

R^i: *If* x_1 *is* A_1^i and $\cdots$ and x_m *is* A_m^i

$$then\ y^i = a_0^i + a_1^i x_1 + \cdots + a_m^i x_m \quad (1)$$

where $R^i (i=1,2,\cdots,n)$ denotes the i th fuzzy rule, $x_j (j=1,2,\cdots,m)$ are input variables and y^i is an output from the i th implication. Furthermore, a_j^i is a consequent parameter and $A_1^i, A_2^i, \cdots, A_m^i$ are membership functions representing a fuzzy subspace. The overall output of a fuzzy model is given as

$$\hat{y} = \frac{\sum_{i=1}^{n} \omega^i y^i}{\sum_{i=1}^{n} \omega^i}, \quad \omega^i = \prod_{j=1}^{m} A_j^i(x_j) \quad (2)$$

where $\hat{y}$ is an output inferred from the fuzzy model, ω^i is a degree of match for the i th fuzzy rule and $\prod$ denotes the minimum operation.

As shown in equations (1) and (2), this fuzzy model describes the nonlinear input-output relation with the piecewise linear equations for the fuzzy partition of the input space. Because this fuzzy model consists of if-then rules, it is intuitively more persuasive toward human beings than any other model and provides the user with a familiar and intuitive manner for modifying a shape with forces. This means that the designer can easily determines which parameters should be used and how much they should be changed to alter shapes correctly.

Another characteristic of the fuzzy model is that it consists of multiple rules, which further strengthens the idea of utilizing the fuzzy model to display various surface deformations and it is enough that only one rule is added to the fuzzy model to display a surface deformation. The proposed algorithms for surface deformation displays are based on this fuzzy model. The deforming actions of a user are used to create a new fuzzy rule that defines the deformed shape of the object and this new fuzzy rule is added to the original fuzzy model to display surface deformation.

The algorithms for surface deformation displays are as follows:

Step1 : Display the original surface using the fuzzy model of the type:

R^i : If x is A_x^i and y is A_y^i ,

$$\text{then } z^i = a_0^i + a_1^i x + a_2^i y \quad (3)$$

Step2 : If a force is applied to the surface, acquire a new rule set R^{new} for a surface deformation. This new rule set is in the general form of

R^{new} : If x is A_x^{new} and y is A_y^{new} ,

$$\text{then } z = z_0 - b_0 \quad (4)$$

The parameters of the new fuzzy rule are determined as follows:

1) The value of z_0 is the z coordinate of the surface without deformation. The value of b_0 depends on both the force and stiffness of the object and we define b_0 as $\alpha \frac{f}{k}$ where f is the force which is applied to the surface, k is the stiffness of the object and α is the calibration factor, which is defined as the ratio of the size of the virtual object to the size of the actual object. If a pressure is applied to the surface, the value of b_0 is altered in proportion to pressure magnitude in the fuzzy model.

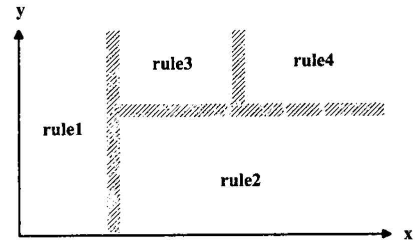
2) A_x^{new} and A_y^{new} are membership functions and in this paper, all membership functions are Gaussian-like and are fully described by their modal values p_x, p_y and spreads q_x, q_y as follows:

$$A_x^{new} = \exp\left\{-\left(\frac{x-p_x}{q_x}\right)^2\right\} \text{ and}$$

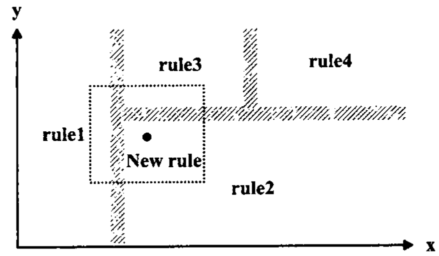
$$A_y^{new} = \exp\left\{-\left(\frac{x-p_y}{q_y}\right)^2\right\} \quad (5)$$

where modal values p_x and p_y of membership function correspond to a point pushed on the surface of an object and the spreads q_x and q_y of the membership function determine the properties of the shape being sculpted. A large values for q_x and q_y result in the deformation of a wide area.

Step3 : Add the newly generated rule set R^{new} of a surface deformation to the original fuzzy model as shown in Fig. 1 and a new fuzzy model is reconstructed to display surface deformation.



(a) without deformation



(b) with deformation

Fig. 1. Fuzzy partition of the input space

Step4 : If another force is applied to the surface, repeat steps a, b and c.

In the above algorithm, the b_0 in the consequent part determines the deformed depth when the surface is pushed. Furthermore users are able to control the region of deformation and the shape of deformation by the parameters of the membership function. Therefore, the new fuzzy rule allows users to manipulate surface geometries, such as curvature and depth of deformation at any point on a surface. To give a comprehensive coverage of algorithms of the proposed method, this discussion can be augmented by a simple example. For simplicity, let the model be two-dimensional although the proposed method can be easily applied to three-dimension. Consider the fuzzy model of the surface representation to contain three rules defined as follows:.

R^1 : If x is $A_x(20,20)$,
then $y=f_1(x)=0.25x+4$

R^2 : If x is $A_x(50,20)$,
then $y=f_2(x)=5$

R^3 : If x is $A_x(80,20)$,
then $y=f_3(x)=-0.025x+6.5$ (6)

where $A_x(p,q)=\exp\left\{-\left(\frac{x-p}{q}\right)^2\right\}$

The consequent parts and the premise parts covering fuzzy sets defined in space x are shown in Fig. 2, and the graphical representation of the surface represented by the fuzzy model is shown in Fig. 3(a).

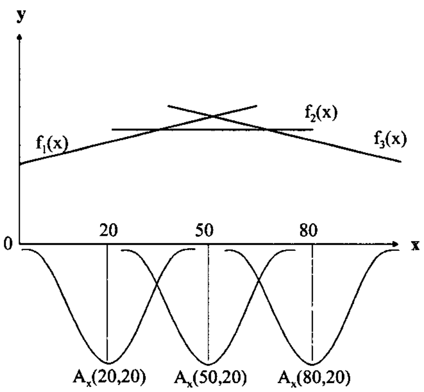
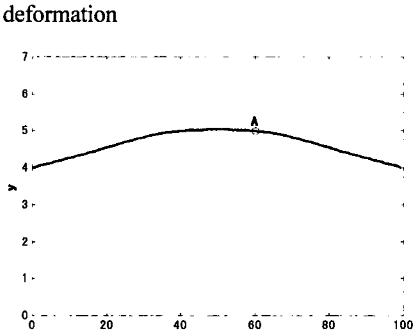
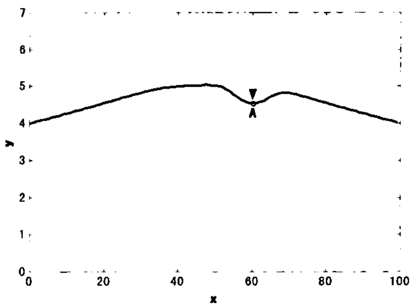


Fig. 2. Graphical representation of a fuzzy model without deformation



(a) without deformation



(b) with deformation

Fig. 3. Graphical representation of a surface

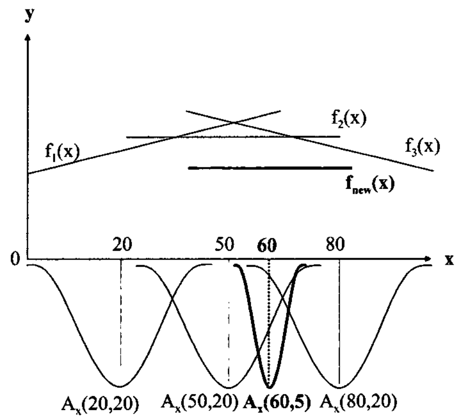


Fig. 4. Graphical representation of a fuzzy model with deformation

Assume that a force is applied to point A on the surface and the x coordinate of point A is 60. To derive a fuzzy model using the proposed method, the steps described above have to be performed and a new rule set is provided in the general form of

$$R^{new}\ :\ \text{If } x \text{ is } A_x^{new}, \text{ then } y=c_0=y_0-b_0 \qquad (7)$$

The essence of this algorithm is an additional space in which the deformation surface is defined. The point which is pushed in becomes the modal value of the Gaussian function, p, which is equal to 60. Depending on the characteristic of an object, the deformation produced by the applied force is changed according to the parameter of the membership function, q and the consequent parameters of the fuzzy model, b_0. Here, we assume that q is 5. The applied force and stiffness of the object are used as the consequent parameters of the fuzzy model. Assuming that the applied force is 5(lb) and the stiffness of the object is 1(lb/in.) and α is 0.2, then, in equation of $b_0=\alpha\frac{f}{k}$, b_0 is determined to be 1. The y coordinate of the surface without deformation is 5 and value of y_0 is 5. Therefore, a new rule set R^{new} for a surface deformation is acquired as follows:

R^{new} : If x is $A_x(50,20)$,
then $y=f_{new}(x)=5-1=4$ (8)

Then by inserting this new rule set into the original rules of the fuzzy model, we obtain a new fuzzy model with four rules. The interaction between the new fuzzy rule and the original rules modifies the original fuzzy model and is used to represent the deformation of the surface as shown in Fig. 3(b). The resulting representation of a modified fuzzy model is shown in Fig. 4. The above simple example shows how to represent the deformation of the surface based on a fuzzy model

III. Simulation and Considerations

To illustrate the approaches proposed in this paper, we show the effect of the deformation according to the change of the parameters in fuzzy model by simulation of plane surface. In this case, a plane surface is represented by only one rule whose consequent part is a constant expression given by following rule:

R^1 : If x is $A_x(10, 100)$ and y is $A_y(10, 100)$,

$$\text{then } z = f_1(x, y) = 3 \qquad (9)$$

where, $A_x(p_x, q_x) = \exp\left\{-(\frac{x-p_x}{q_x})^2\right\}$ and

$$A_y(p_y, q_y) = \exp\left\{-(\frac{x-p_y}{q_y})^2\right\}$$

If a force is applied to the above plane surface, a new rule set R^{new} for surface deformation is added. Assume that each new rule set of following two cases is added for surface deformation respectively:

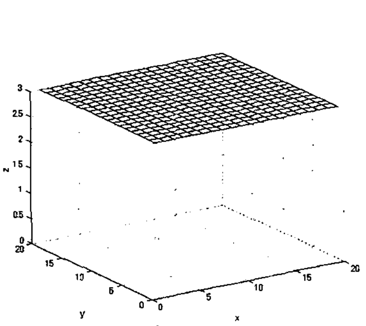
Case1 : If x is $A_x(10, 4)$ and y is $A_y(10, 4)$,

$$\text{then } z = f_{new}(x, y) = 2 \qquad (10)$$

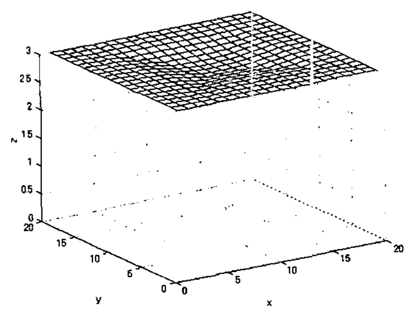
Case2 : If x is $A_x(10, 4)$ and y is $A_y(10, 4)$,

$$\text{then } z = f_{new}(x, y) = 2.7 \qquad (11)$$

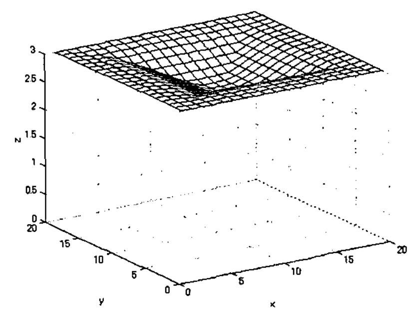
In the two cases, we only change the consequent parameters of the fuzzy model to observe the effect of deformation according to the change of the consequent parameters. Fig. 5. shows a surface deformed subject to each case. As shown in Fig. 5 as the value for the consequent part increases, the depth of deformation increases because the depth of deformation depends on the value of consequent part.



(a) Before deformation



(b) After deformation(z=2)



(c) after deformation(z=2.7)

Fig. 5. Deformation according to the change of the consequent parameters

On the other hand, each membership function has its own deformation characteristic, which is defined by the region it affects and the shape it creates. Now we will show the deformation characteristic according to the change of the parameters of the membership functions. First of all, consider following cases that show the deforming effect according to the change of the modal values p_x and p_y of the Gaussian-like membership function, where we only change the modal values p_x and p_y of the membership functions:

Case1 : If x is $A_x(10, 3)$ and y is $A_y(10, 3)$,

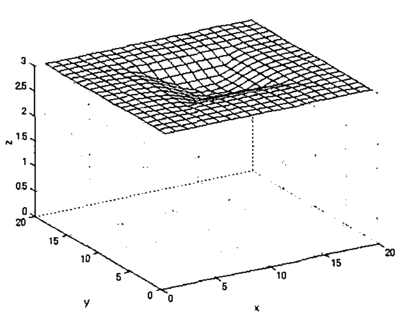
$$\text{then } z = f_{new}(x, y) = 2.3 \qquad (12)$$

Case2 : If x is $A_x(7, 3)$ and y is $A_y(7, 3)$,

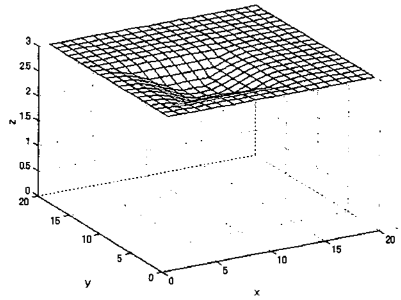
$$\text{then } z = f_{new}(x, y) = 2.3 \qquad (13)$$

Case3 : If x is $A_x(13, 3)$ and y is $A_y(14, 3)$,

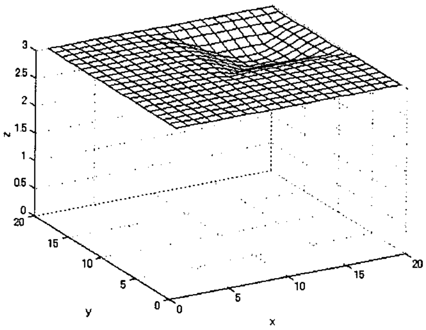
$$\text{then } z = f_{new}(x, y) = 2.3 \qquad (14)$$



(a) Deformation(p_x=10, p_y=10)



(b) Deformation(p_x=7, p_y=7)



(c) Deformation(p_x=13, p_y=14)

Fig. 6. Deformation according to the change of the membership functions.

As shown in Fig. 6, if the modal values for the Gaussian-like membership function are changed, the point pushed is also changed to the position corresponding to the moral values and we can say that these moral values of the membership function correspond to a point pushed on the surface of an object.

Next, we will show the effects of the deformation according to the change of spreads q_x and q_y of the membership function. Consider following three cases, where only the spread values of the membership function are changed.

Case1 : If x is $A_x(10,2)$ and y is $A_y(10,2)$,

$$\text{then } z=f_{new}(x,y)=2.5 \tag{15}$$

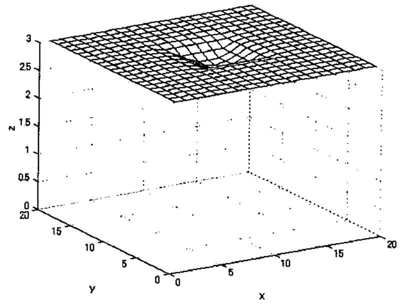
Case2 : If x is $A_x(10,4)$ and y is $A_y(10,4)$,

$$\text{then } z=f_{new}(x,y)=2.5 \tag{16}$$

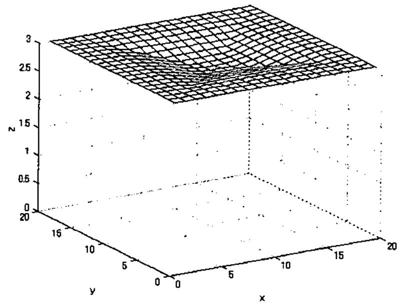
Case3 : If x is $A_x(10,6)$ and y is $A_y(10,6)$,

$$\text{then } z=f_{new}(x,y)=2.5 \tag{17}$$

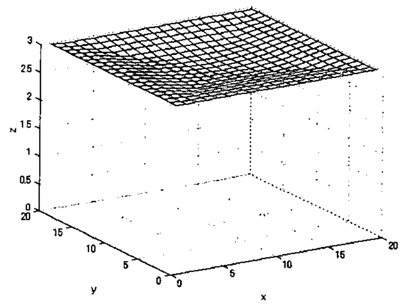
For each case, the graphical results are shown Fig. 7(a), (b), and (c) respectively. For a small value of spreads, the deformation occurs in a small neighborhood of a point pushed. Large values for spreads result in deformation of wide area and curve more smoothly connected. Thus, users are able to control the region of deformation and the properties of the shape being deformed by adjusting the parameters of the membership function.



(a) Deformation(q_x=2, q_y=2)



(b) Deformation(q_x=4, q_y=4)



(c) Deformation(q_x=6, q_y=6)

Fig. 7. Deformation according to the change of the membership functions.

The above illustrative examples clearly show the role of the parameters in the fuzzy model. Computing thus all the parameters of fuzzy model, we get the corresponding fuzzy model of the surface deformation. The linear equations in the consequent part determine the depth of the deformation and the membership function determines the area of the deformation and properties of the shape being sculpted. Therefore, designer can easily determines which parameters should be used and how much they should be changed in order to alter shapes as they want.

The above simulation studies have clearly indicated a suitable performance using the proposed method and showed the advantages of the proposed approach.

From the standpoint of interactive design, the computational time is very important and the proposed method is simple and effective for quick response and real time operation. However, the present method will be improved in different ways for more complex deformation tasks. If we increase the number of fuzzy rules, the shape deformed may seem to be better but the calculation time will also increase. The computational time and the accuracy of the deformed shapes are trade-offs. Obviously, we are dealing here with an easy and well defined object, however, the proposed method can be easily applied to much more complex shape representation. On the other hand, the proposed deformation method is indirect, since the user changes the parameters in order to change the surface shape. In the proposed method, however, the specified region of the deformation is described by the parameters of the membership function and the depth of deformation is controlled by the consequent parameters of the fuzzy model. This means that the proposed method can be easily applied to the direct deformation method where the parameters that represent the shapes are changed automatically so as to deform shapes appropriately to the user's deforming action. As a future work, more research will be conducted using the direct deformation method.

IV. Conclusion

In this paper, a new method of displaying a surface deformation is proposed using a fuzzy model and its validity is verified through computer simulation. The most distinctive features of the proposed method are its simplicity and flexibility. The region and shape of deformation is defined by membership functions and the depth of the deformation is defined by the consequent part of the fuzzy model. And, it is sufficient that only one additional rule be added to the fuzzy model to display a surface deformation since the fuzzy model has parallel structures. These simple algorithms reduce the number of calculations and are therefore computationally extremely efficient, which allows for fast enough evaluation for real time operation. However there are still many challenge problems such as much more complex shape representation and practical applications. The real ability of the proposed method will be increased when it is combined with a nano-teleoperation system with visual feedback which is now under study[9].

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