THE METHOD OF RESPONSIVE SHAPE DESIGN BASED ON REAL-TIME INTERACTION PROCESS

ZHE GUO[1], CE LI[2] and YIFAN ZHOU[3]
[1]*Hefei University of Technology*
[1]*guogal@hotmail.com*
[2]*Wuhan University*
[2]*26650299@qq.com*
[3]*University of Hawaii at Manoa/Tongji University*
[3]*yifanz@hawaii.edu*

Abstract. This project focuses on how real-time motion interaction caused by people could put potential drivers for parametric design innovation, which would enhance the link between form trigger and result. Begin with discussing of background in interactive digital design, this article starts from three aspects in turn. First, the shape generating method based on a mesh geometric data format is discussed, which is the precondition of this research. Then, several kinds of behavior interaction are selected to be the input data which directly or indirectly trigger and affect this responsive shape formation process mentioned in the former part. In the last part, this research will summarize and propose a complete set of interactive behavior-oriented responsive digital prototyping design and propose several corresponding application scenarios.

Keywords. Mesh algorithm; actuated interaction design; generative design.

1. Introduction

After years of accumulation of parametric design methods and digital manufacturing technology in the field of computer-aided architecture, interior and industrial design, a kind of consensus has been established, which makes these digital processes more intelligent and intuitive for designers and users.

In the past few decades, there have been a series of groundbreaking steps in developing interactive research by various research groups. Most of these attempts share a common goal in creating human-inspired shape morph methods. Tongji digital research group has established a set of complete system, which could convert human voice characters into a digital complex pattern that could be generated and displayed in real-time (Zhao, 2019). Expending plane to space, some research focused on looking at the interface between remote sensing and a responsive environment to explore the possibility of an interactive architecture that conditions and responds to the user's movements (Farahi, 2013), this method has not only been applied in architecture installation but also showed this deeply

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formation potential in body wearable architecture (Farahi, 2016). In the process of interaction with shapes, how can human behavior characteristics be captured and translated into triggers to control the morph of shapes is the key factor discussed in Fox's research (Fox, 2012).

It not hard to see the enthusiasm of designers to build an intelligent response deformation system by constructing the digital chain which makes it possible for designers and users to put intervene caused by human behavior into every phase of the digital design process to influence the direction of the results. The small difference of various individual behavior will lead to the richness of information reflected, which is exactly the charm of interaction design because it changes the stereotyped shape rule and endows the design result with uniqueness. As Behnaz Farahi states, "the main attempt in such a work, is to engage with geometries and shapes in order to understand dynamic material behaviors in relation to the specific human body", this project attempts to explore a method that is able to link complex shape generation and simple movement by converting human gestures into morph trigger. In this whole process, the role of designers will be changed from making a specific shape to formulating generating rules, meanwhile, users will participate in design decision making by intentional or unconscious behaviors, which is able to place more modality possibilities in it.

2. Methods of shape generation and interaction mode

2.1. RESEARCH ON SHAPE GENERATING RULES

2.1.1. Base mesh geometry attribute

In 3D computer graphics and solid modeling, a polygon mesh is a collection of vertices, edges, and faces that defines the shape of a polyhedral object. Mesh geometry has a high degree of freedom and simplicity in the expression of complex geometric form operation with concise geometric definition and data storage format. The faces usually consist of triangles (triangle mesh), quadrilaterals (quads), or other simple convex polygons (n-gons). Meshes are used for rendering to a computer screen and for physical simulation which is the best choice as the complex geometry manipulation in this research. Among types of mesh format, the face-vertex mesh is selected in this research that represent an object as a set of faces and a set of vertices, the order of vertices determines the direction of the mesh normal. This is the most widely used mesh representation, being the input typically accepted by the modern graphics hardware. The mesh consist of quads, according to the closeness of its edge can It can be classified into two categories, cube mesh, and grid mesh, which attribute showed in fig.1. These two meshes types are used as the base mesh geometry in our research.

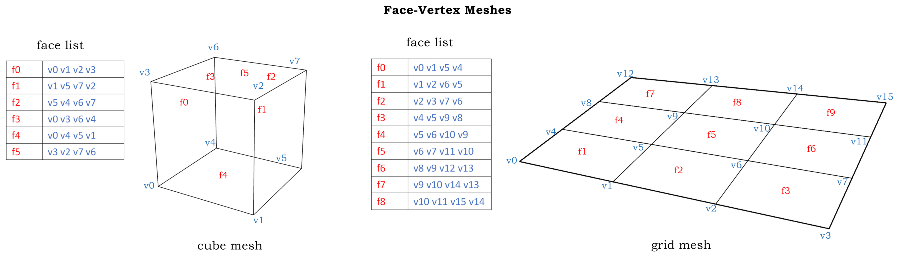

Figure 1. Face-Vertex Mesh definition format.

2.1.2. Mesh generation

One simplest quad mesh defined by four spatial vertices spatial coordinates and the order of vertices that defined as Face. The basic rule of shape forming in our research is based on the operation of mesh vertex. By moving certain vertices into a new spatial position and keeping the original vertex order in every face, the original mesh can realize topology deformation under unified rules. In the process of vertices movement, a mesh subdivision algorithm called Catmull-Clark is used to generate mesh detail and to make the whole shape successive. This subdivision algorithm can subdivide polygons with arbitrary topology is a technology used in 3D computer graphics, which creates smooth surface by subdivision surface modeling method. It was designed by Edwin Catmull and Jim Clark in 1978 as a generalization of bi-cubic uniform B-spline surface to arbitrary topology (Catmull, 1978). Starting from the mesh of any polyhedron, this is considered to be the advantage of the algorithm. The new polygon surface created in In every subdivision operation can be applied with the same subdivision rules, which are recursively defined by using the following refinement scheme. To start with the whole subdivision operation by taking a simple quads mesh as example, we defined all vertices, edges and face in the mesh separately as origin vertex, origin edges and origin face:

- For an origin face with vertices V1, V2, V3 and V4, added as a new “face point” Vf as follow:

$$Vf = \frac{V1 + V2 + V3 + V4}{4} \tag{1}$$

- For an origin edge, suppose that the two vertices of Ve on one side are v and w, and the two adjacent faces are F1 and F2 (the vertex of the face has been calculated as Vf1 and vf2 in former step). So the new “edge point” Ve corresponding to this edge is:

$$Ve = \frac{v + w + Vf1 + Vf2}{4} \tag{2}$$

- For an origin vertex V, suppose Q is the average value of the face point Vf of the polygons adjacent to V, V is adjacent to n edges, and R is the average value of the midpoint of the edges adjacent to V, then the new "vertex point" V0 after adjustment is:

$$V0 = \frac{Q}{n} + 2 \cdot \frac{R}{n} + (n - 3) \cdot \frac{V}{n} \tag{3}$$

- How to generate edges after getting new vertices is the next important step. We follow next two rules: Firstly, each face point Vf is connected to the edge point Ve corresponding to the edge surrounding it to create new edges. After each vertex is adjusted, the new vertex point V 'is connected with the edge point Ve on its adjacent edge to create the other edges.

After a thorough study of this mesh generation algorithm, one conclusion can be drawn that the way these three basic vertices (face point, edge point, and vertex point) move will decide the whole mesh shape. In other words, by putting more rules to Catmull-Clark generation algorithm shows in Figure 2, via one unique or several functions to influence weights value determined face point and vertex point movement (edge point is defined by face point, so these two change will have internal correlation), abundant morph can be produced in these process.

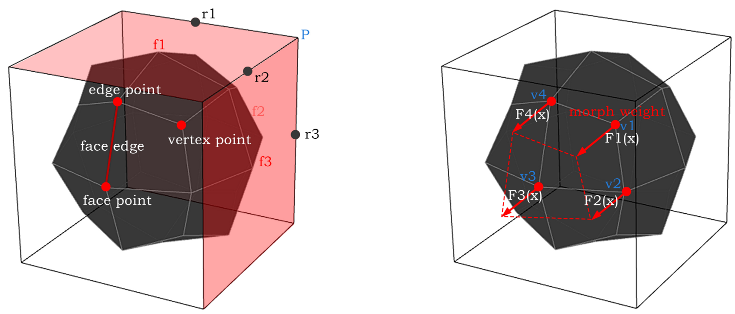

Figure 2. additional rules to Catmull-Clark algorithm.

2.1.3. Shape morph rules

In the cube mesh manipulation process, several different methods for calculating the point position transformation are established, which are expressed as the expression F(). The amplitude of vertex extrusion, the degree of smoothing, and the uniformity of disturbance are defined respectively as function Fa(), Fs(), and Fd(). Based on the traditional Catmull-Clark algorithm, the newly generated vertices after each iteration operation will participate in the next manipulation operation. Due to the certainty of the morph rules, this shape operation method can produce similar deformation results of the whole through subdivision logic. By change every weight function, various mesh shapes have the same topological configuration can be designed efficiently.

From the original cube mesh as the initial state of shape operation, each iteration will generate outward vertices by changing points spatial coordinate and add these new points to the mesh vertex set. Where the weight of the moving amplitude is controlled by the function Fa(). Parameter h determines the degree of vertex deviation as shown in Figure 3.

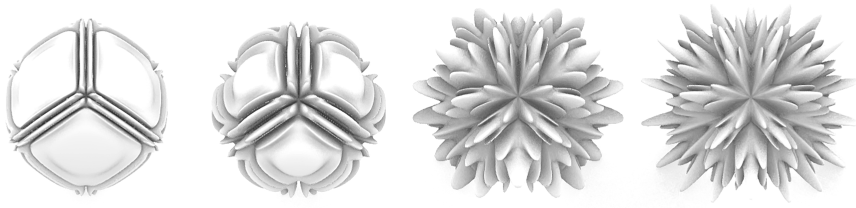

Figure 3. Fa() function define the weight of face extrude amplitude.

In one complete iteration, after the process that a new mesh face is formed by ordering the vertices as the original mesh order, the Catmull-Clark subdivision algorithm will run once to make every edge smooth(shown in Figure 4). During this step, the other two functions are applied to control subdivision weight in order to create more small bump detail onto the mesh surface. In the original Catmull-Clark algorithm, the new face points, edge points, and vertex points are generated according to the established moving rules in the subdivision process. While in our study, another additional function Fs() (like Fa() function) is added to control the displacement weights of the three points belong to a mesh. When the definition of the movement attributes of these three types of points is reorganized, it has more detail tension than the formal results of subdivision algorithm without additional function interference. As shown in Figure 5, when the face point, edge point, and vertex point are operated respectively using the same function and parameter, the results of subdivision form shows great difference. By combining different interference weight values, various forms of shape morph results can be generated which shows that this redefined algorithm has great derivative potential.

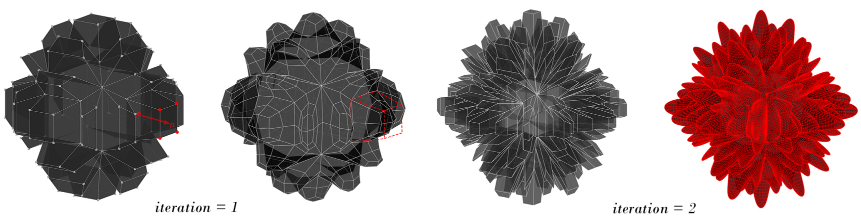

Figure 4. redefine Catmull-Clark algorithm by changing morph weight.

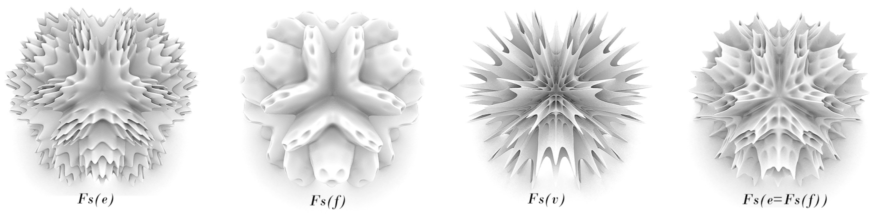

Figure 5. degree of smoothing, e means edge point, f means face point, v means vertex point.

Farther more, one more function can be added in the process we named as Fd() means uniformity of disturbance on the whole mesh. This function determines whether the vertices belonging to the mesh face should be extruded by setting the judgment conditions for the mesh face (Figure 6). Meanwhile, the Fs() function could be applied to subdivide the surface disturbance.

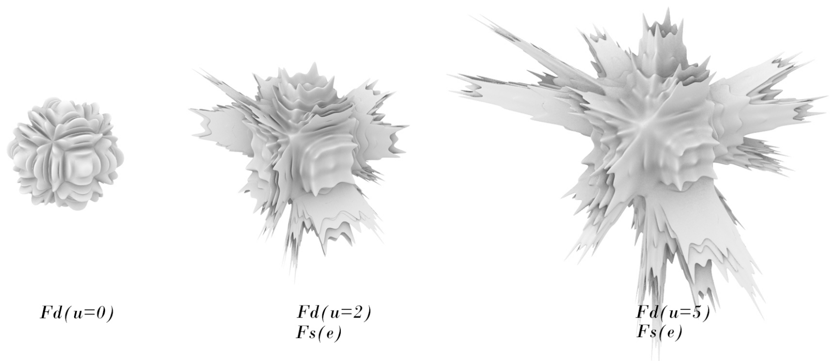

Figure 6. the uniformity of morph disturbance.

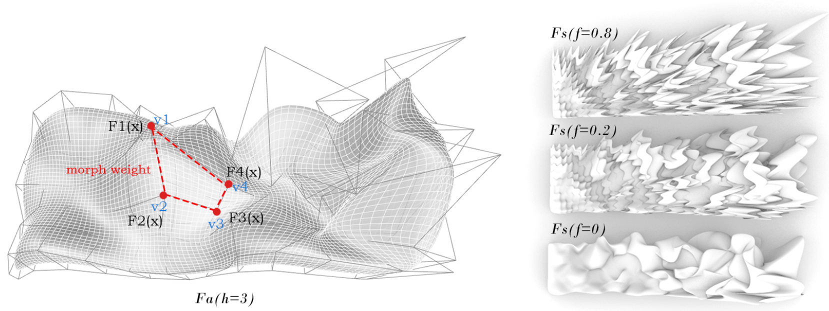

Figure 7. grid mesh basic morph manipulation define by Fa() and Fs().

These morph weight functions we build and apply here is be supposed to link with specific movement data collected and remapped by some kind of human behavior detecting equipment, which will be detailed in the next chapter. Consider the form operation of grid mesh, the morph rules similar to cube mesh are applied. From the original grid mesh as the initial state of shape operation, only the first iteration will generate outward vertices by changing points spatial coordinate randomly and add these new points to the mesh vertex set. Where the weight of the moving amplitude is controlled by a set of Berlin noises the function is defined as Fa(). Parameter h determines the degree of vertex deviation as shown in Figure 7. The higher the value of h, the greater the extrusion range.

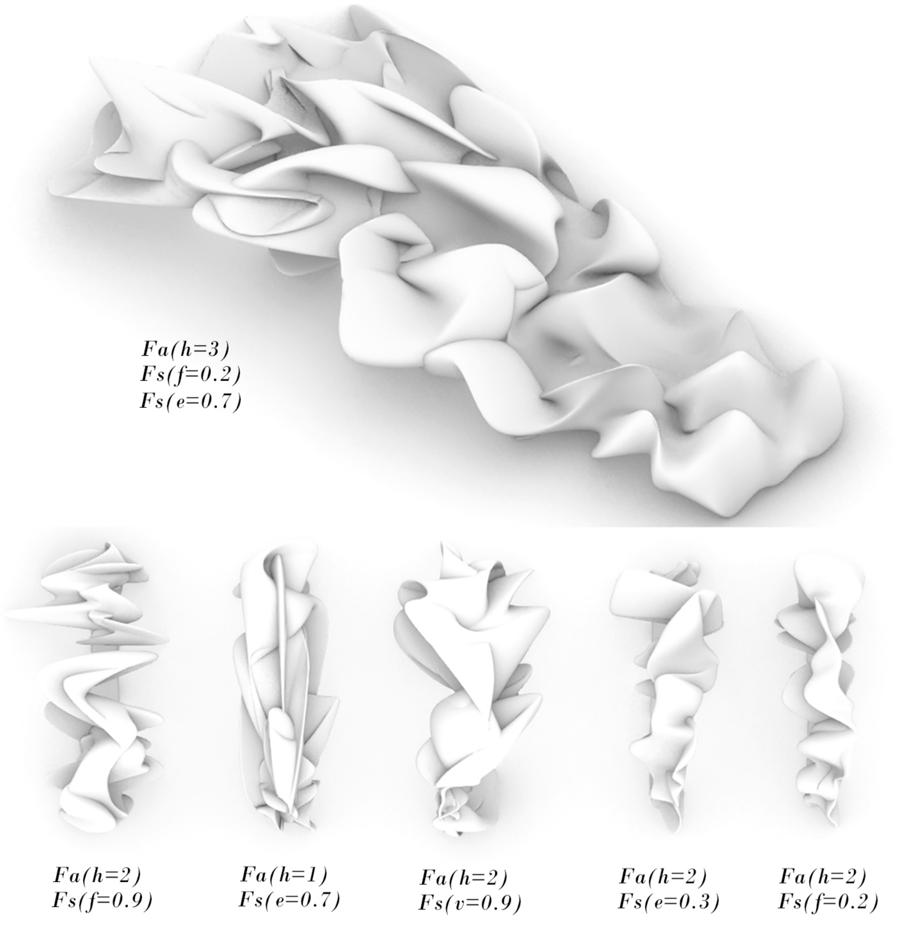

Figure 8. shape morph results using combined weight functions.

In the following subdivision iteration process, adding the weight function of each face point movement in the process of smoothing the mesh can form the subtle surface bump details showed in Figure 7. The value here represents the extent of turbulence. 0 value means no move for face point while 0.8 means the ratio of the vertex movement distance to the average extrusion value of the four vertexes touching the face. Via applying composite interference weight functions, we created some experimental shape morph which intuitively shows the difference formal beauty compared with the operation of cube mesh although the same morph rules applied in this process. The form results are shown in Figure 8.

2.2. INTERACTION DESIGN PROCESS

2.2.1. Workflow

In this research, a complete workflow for the part of interaction design is built as Figure 9 shows. By using behavior sensing equipment, such as leap motion or Kinect, a set of behavior characteristic data can be transformed into a series of spatial coordinate in real-time, which is supposed to be translated into the conditions that trigger the mesh shape generation through the mapping algorithm. In the last parts of how we can display this whole process, the VR and AR technique could be the first choice in follow up with further research to make this interactive design process more real and intense.

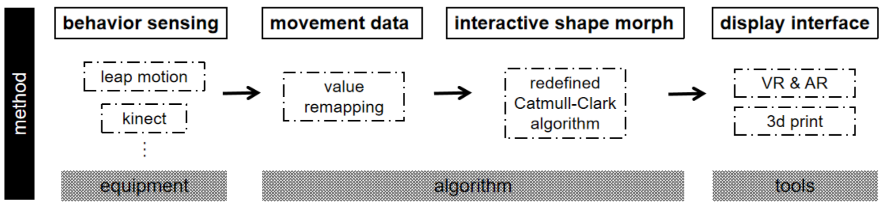

Figure 9. interaction design process.

2.2.2. Data remapping rules

In order to develop a responsive relationship with the user, these shape design systems need to be able to sense the behavior of the user by employing gesture sensors or infrared motion capture technologies in order to detect physiological responses such as range of limb movement. Ultimately, these shape design systems should be capable of using their dynamic morph to ‘elicit’ certain movement responses in the user. In this way, the interaction method turns one-way mode into two-way and will display more potential relationship between explicit shape result and implicit movement process.

Take the interaction design of the leap motion gesture capture device as an example: The leap motion device can output the spatial point coordinates of all finger joints of each hand, a total of 20. These data can be used to approximate the types of hand movements. Four gesture statements are defined showed in Figure 10, which are two fingers(two points), one finger(point), palm, and fist. In the process of hand movement, the certain position of these parts of hands will be updated in real-time, and the movement distance can be obtained by calculating the coordinates with the previous hand state. Through data mapping, the distance of the displacement is translated into the input value of those shape morph weight function, which can result in mesh generation and transformation.

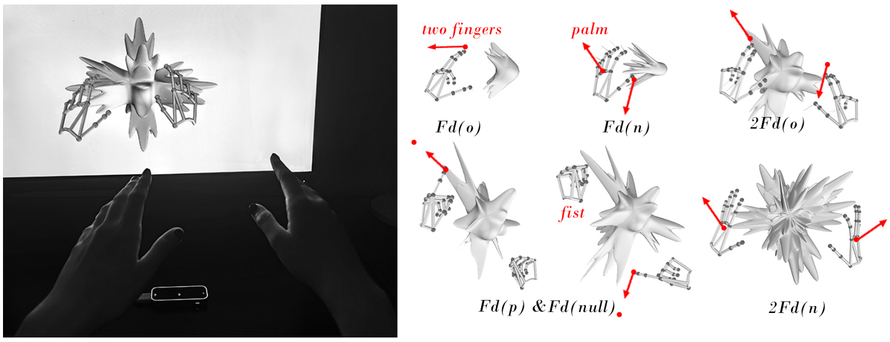

Figure 10. finger motion capture and data mapping into shape morph function.

Furthermore, a new gesture feature, the speed of palm movement could be defined and its data could also be linked to the function Fs() to realize detailed subdivision generation of mesh surface disturbance by quickly waving the palm (Figure 11). In a larger scale of behavior sensing, whole-body infrared motion capture devices such as Kinect will reflect its important value. Using the same data mapping method as hand motion capture we studied in this research, the motion data of body joints also can be translated into the input data of mesh morph function.

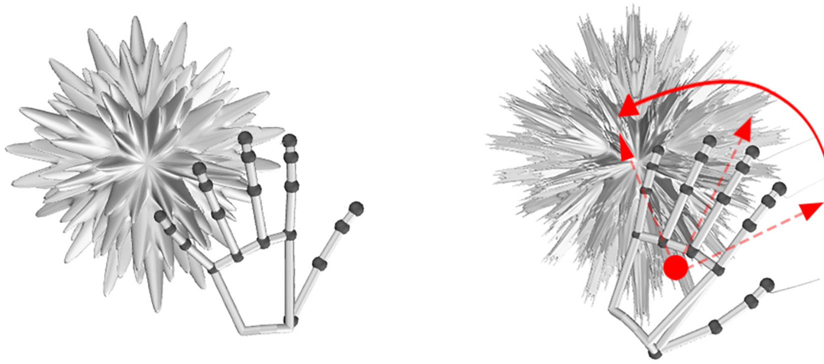

Figure 11. interactive action influences the generation details.

3. Conclusion

This research starts from mesh shape generation design, by decomposing and rewriting the iterative subdivision algorithm, we can formulate the external rules of the specific shape generation and transformation, and the preset data input terminal. The responsive form design method established in this project is completed by a computer algorithm, which will improve the speed, richness, and completion of the customized shape design process. The data input by different hardware can control the final modeling form, so this interactive design method established in our study has a very wide range of application expansibility. This kind of interactive design provides a low threshold and high richness for both designer and user in the digital design process through a way of natural participation. The practical value of this method is reflected in its reasonable combination with a variety of application scenarios and contents and has great market potential in digital art, cultural and creative design, and interactive experience.

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