

Component Technologies and Education Activities Required for Projection Mapping

プロジェクションマッピングに必要とされる要素技術と教育活動

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Regardless of the size of targets and the persons who create them, a key question remains the same: what kind of CG animation will be appropriate for projection mapping? In the past three years we studied projection mapping by integrating computer graphics, arts, architectures and algorithms, and found that component technologies, namely two effective 3D modeling methods, were useful in projection mapping. Students were trained to use them for projection mapping, and examples were given to show applications.

Keywords: Projection mapping, Education, Computer graphics, Component researching, Modelling methods

1. Introduction

Although disagreement exists on whether projection mapping is science or not, and its evaluation is subject to cultural and social factors, a projection mapping is generally considered successful if it displays a comprehensive beauty of multi-elements, such as shape, texture, motion and music, in addition to smart use of computer graphics technology.

Projection mapping is an application of computer graphics technology, but it differs from common computer graphics in some aspects. For example, in the Ralph Lauren London digital innovation fashion show (Fig.1), we can see both the outside and the inside of the building, the stairs, corridors, and fashion modelers walking through the hall. Projection mapping requires not only building structure, but also dynamic animations, such as wall breaking, glass cracking, or pillars falling down. It requires the animations that featured with as fantastic, fairytale-like, magical, or romantic effects.



Fig.1 Ralph Lauren London digital innovation fashion show of projection mapping ¹⁾

We usually reconstruct a building and create its digital CAD model exactly according to its blue drawings. For projection mapping, however, such exacting model is usually unnecessary. Instead, only the front wall facing to the projectors is required. Exacting model has its limitations. For example, to generate dynamic animation we need to model the building in extended ways, adding structures that do not exist in the blue drawings and dividing walls into smaller pieces with purpose. More importantly, we must ensure that these extensional structures agree with the overall shape of the building for identification purpose.

This research aims to solve the above challenges in projection mapping from both design and technology aspects. Specifically, models for effective projection mapping on various buildings are identified, implemented with computer graphics, and animated at various times, through following processes:

- Investigation: By analyzing YouTube videos, we have found some modelling methods that have been successfully used in projection mapping event.
- Algorithm: We have created algorithms and programs to implement the modelling methods.
- Education: We have produced educational kits to help students learn the modelling methods and put the skills in practice in projection mapping.

2. Investigation and Analysis

Since the BEIJING Olympic Games in 2008²⁾, projection mapping has become popular in many countries. In Europe, it is widely used in advertisements^{3, 1, 4, 5)}, stages^{6, 7, 8)}, and entertainments. It has got popularity in Japan, helped by the amazing performances in Tokyo station⁹⁾ and Tokyo Disneyland¹⁰⁾. Various videos of extraordinary projection mapping events can be found in YouTube, not only projected on buildings but also on cars^{11, 12, 8)}, sports shoes¹³⁾, fish pool in aquarium¹⁴⁾, and even human body¹⁵⁾. Projection mapping would help to make a profit in developing sightseeing and reconstructing of local community^{14, 10, 16, 3, 17, 18)}.

Most projection mappings are based on a principle that the locations of projectors, viewers, and object are constant. Even interactive projection mappings that change mapping images according to a live performance still keep the principle. For example, projection mapping on piano¹⁹⁾ visualizes the player's pressing keys in real time during which the locations of piano, the projector hanged overhead the piano, and viewers surrounding the piano all remain the same. Only in a few cases, such as Box²⁰⁾, images are projected on moving object to show the culmination of multiple technologies, including robotics, image processing, and 3D computer graphics.

We investigated into a lot of *videos of projection mapping (projection contents)* on YouTube. These contents have been repeatedly accessed. They have also played an important role in promoting the innovative technology of projection mapping. We selected 50 projection contents for analyzing the technologies commonly used. 35 of them, created by professionals, were projection mapping on famous buildings. From both art design and technical aspects, they are at the highest level and worth to be studied, summarized and referenced. 15 contents used for the projection mapping on non-building objects, such as shoes, miniature models, or cars. Much smaller than buildings, these non-building objects possess more complexly curved structure. They also had a high reputation among web audiences since they gave fresh, original and innovational idea about projection mapping.

Two methods were found in frequent use (accounting for more than 60% of the selected contents) and their common features in design and technology were briefly discussed.

- **Method 1:** designated as *rind style modelling*. It is commonly used in paintings and illustrations. Fig.2 shows the famous painting of M. C. Escher. It expresses a rind of apple, but giving a clue for it being recognized as a human being. It is a curiosity of human vision that the rinds wrapped around can show three-dimensional shapes.



Fig. 2 Rind, by M. C. Escher, 1955

Fig.3 shows examples of projection mapping in rind style. The left picture shows projection mapping on building ¹⁸⁾, and the right on a flat board ²⁰⁾. Both consist of as many layers of rind to represent three dimensional shapes.



Fig. 3 Examples of projection mapping using rind style modelling ^{18, 20)}.

- **Method 2:** we call it *block based modelling*. Similar to the use of bricks for the construction of old buildings, many projection contents using cubes or boxes to model buildings (Fig.4). This modeling has a great advantage in animating. A specific pose or expression was assigned to every block, a program was used to control an array of blocks. By timely and individually changing each block's location, orientation, size, or color, plenty of interesting animations were created. A challenge for students is: watching videos on YouTube would not tell them how to implement the modelling. They need details in instructing algorithms and coding, which creators usually did not describe and give out. This demand-supply discrepancy prompted us to study algorithms, develop original source codes, and prepare educational kits for students to learn this modelling method.



Fig.4 Examples of projection mapping using block based modelling ^{17, 21, 22}.

3. Algorithms and education kits

Here we described algorithms and gave examples, which would:

- Give students a concrete simple 3D formation as a projection mapping object;
- Teach students to establish a digital model step by step: decide vertices, construction polygons, and draw polygons;
- Teach students how to add transformation to create animation over time; and
- Teach students how to control parameters to obtain variations and animations.

3.1 The algorithm of rind style modeling

To explain the rind style modelling we assume the target object is a simple sphere, and the algorithms are described as follows:

Step1: Set an array of vertices on the surface of the object

Constantly divided N layers by a plane moving from low to high level. Use parameter $n = 0, 1, N-1$ to index each layer.

For each layer, set M vertices on its contour, and use a parameter $m = 0, 1, M-1$ to index each vertex clock-wisely. Connecting these vertices will result in a ploy-line that represents the contour the best (Fig.5- (a)).

- For each vertex, indexed by $P(m, n)$, its three dimensional coordinates $(X, Y, Z)_{(m, n)}$ are to be decided.

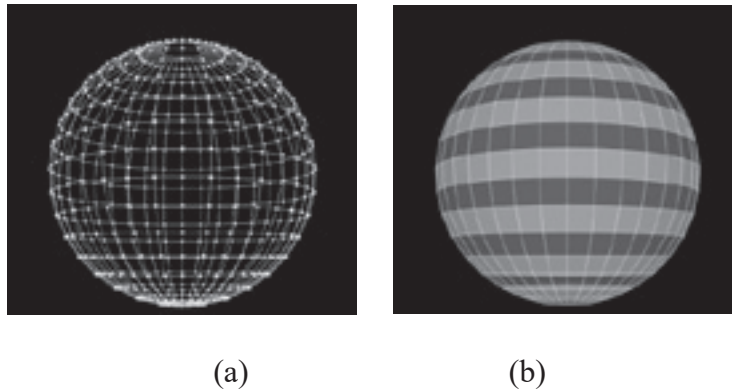


Fig.5 A sphere in rind style modeling

Step2: Define polygons based on the vertices (Fig.5-(b))

- From low to high level, create $M*(N-1)$ quadrangular polygons, each of which $Q(m, n)$, $m = 0, 1, 2, \dots, M-1$, $n = 0, 1, 2, \dots, N-2$, is defined by the four vertices $P(m, n)$, $P(m+1, n)$, $P(m+1, n+1)$ and $P(m, n+1)$.
- For each polygon $Q(m, n)$, set its color $(r, g, b, \alpha)_{(m, n)}$. Here, we set polygons on the same level the same value of r , g , b , but for polygons on odd number levels, we use white transparent color $(1, 1, 1, 0.5)$.

Step3: Draw polygons in perspective 3D virtual space

- From low to high level, draw the $M*(N-1)$ polygons. Here, we draw each polygon twice, once in filled surface, and the other in wireframe. Obviously, polygons on the backside of the building will be obscure since the polygons on the front side will hide them.

Step4: Change polygons' color in animation (Fig.6)

- We can set polygon's color varying with level parameter n , and with timer parameter t . This

enables polygons' color changing automatically over time.

$$(r, g, b) = \text{abs}(\sin(0.2*t + 0.1*n)) * 255$$

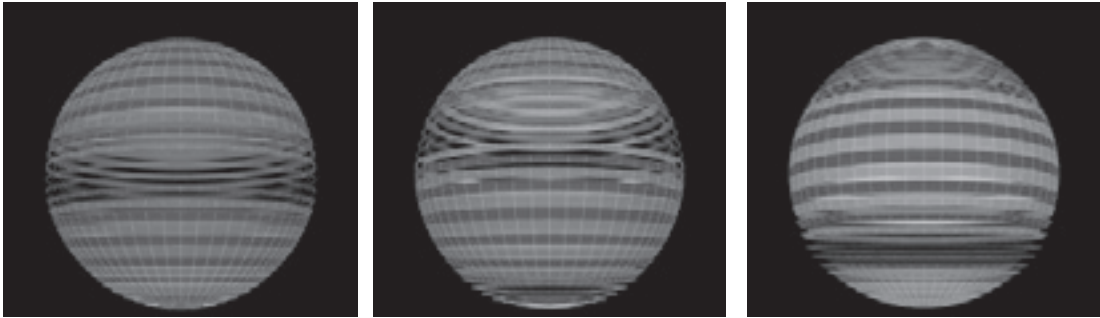


Fig.6 Vary the color of rinds with layer parameter n and time parameter t

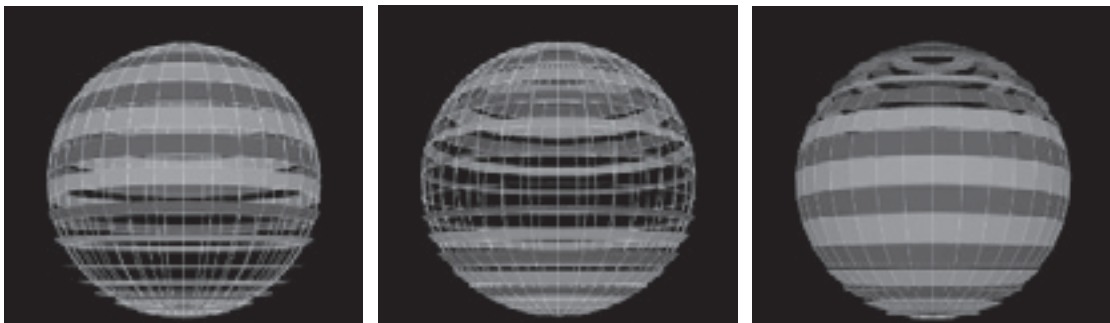


Fig.7 Vary the width of rinds with layer parameter n and time parameter t

Step5: Change polygons' formation in animation (Fig. 7)

- We can scale the width of rinds, making gaps between the rinds thinner. We use the following codes to control the gaps moving as a wave from bottom to top with certain rhythm. Through the gaps between rinds, we can see the backside of the sphere.

$$\text{Scale}(1.0, \text{abs}(\sin(0.1*n + 0.3*t)), 1.0)$$

3.2 Block based modelling

Here we use a flat wall to explain the algorithm. Block based modelling method use solid cubes of the same size to construct walls, by placing cubes together without a gap in between.



Fig.8 The result of using *code example 1*, some blocks moving forward or backward



Fig.9 The result of using *code example 2*, another case of blocks moving forward or backward

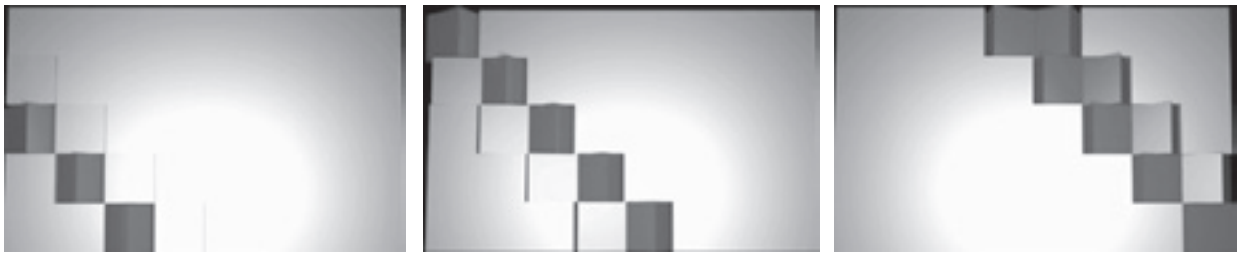


Fig.10 The result of using *code example 3*, some blocks rotating 90 degrees

Step1: Define boxes constructing the wall

- Represent each wall as an array of $M*N$ cubes of the same size. For the beauty of modelling, we may adjust M and N , to expect a cube with an integer edge length e ,

$$e = \sqrt{(w*h)/(M*N)}$$

Step2: Show the wall, drawing $M*N$ solid blocks one by one with following codes

- Each cube is independent of others and has its specified index number, location coordinates, color, and orientation.

block wall of orientation (1, 0, 0)

R, G, B = 1, 0, 0 #moving blocks' color

for y in range (-4, 4):

for z in range(1, 6):

bpy.ops.mesh.primitive_cube_add()

bpy.context.object.location[0] = -6 # x coordinate

*bpy.context.object.location[1] = y * 2 + 1 # y coordinate*

*bpy.context.object.location[2] = z * 2 + 1 # z coordinate*

#code example 1

*Move(((z-1)*20+ (y + 2)*20, "x", 40, "+", 5, R, G, B)*

#code example 2

*Move((z-1)*20+ abs(y)*20, "x", 40, "-", -5, R, G, B)*

#code example 3

*Rotate((z-1)*20+ (y + 2)*20, "y", 40, "-", R, G, B)*

R, G, B = 1, 1, 1 # non-moving blocks' color

Step3: Animation of moving blocks (Fig.8)

- We can move a block forward or backward to cause an uneven part appearing on the flat wall. A block changes color from white (1, 1, 1) to red (1, 0, 0) while moving forward, and returns to white color again while moving backward.

In teaching student programming skills we made a lot effects on setting parameters. By using the same method *Move()*, but setting different values for parameters as *example code 2*, we can easily create various animations that the uneven part appears and spreads in different ways (Fig.9).

Step4: Animation of rotating blocks

- If we select to use a method of *Rotate()* as *example code 3*, we can create an animation as if a wind flows over the wall. The wind rotates the cubes on its trace, spreading in the blocks in the same way as about *Move()*, since the parameters are the same.

Step5: Animation of individual block

If we don't like all the cubes moving in the same way, we may set some individuals separate motions. For example, two cubes exchange their locations; cubes on top of the wall jump up one by one; and some cubes rotate and show textures mapped on their backside in order to give a picture message. Such separate motions personify blocks, giving them cute features people are more familiar with.

With the strong support of hardware and environment from our university, we started a special course in 2014 to teach projection mapping for senior students, many of them had taken prerequisite courses in computer graphics and animation. Meanwhile, they are eager to learn this new knowledge and skill for better employment. These positive factors make it easy for the teaching.

In academic year from April to March, we spent 9 months for the education program. In the first month, students used our education kits to learn about modeling methods. They then started to practice projection mapping on real buildings from July to December. In the final months, they summarized their activities, wrote graduation theses, and gave presentations of their work. The following section briefly summarizes students practicing activities.

4. Practices and Results

Since 2014, this education program has been performed for four years. Every year about 10 senior students took part in the program, focusing on learning, studying, and practicing of projection mapping. We have carried out four times of projection mapping events on two buildings on campus, one is the building *No.27* another the *KIT radio broadcast station*. The former (Fig.11-(a)) is a gray concrete building marked by its section formation of octagon (10 meters high, 9 meters wide). The latter (Fig.11-(b)) has a big flat wall of glass and curtain behind (8 meters high, 12 meters wide).

We only selected the two buildings mainly due to the capability constraints. We only have two projectors of 7000lm (*EPSON-EB-G6350*), covering an area of 12x12 meters; in-availability of big enough open space in front of the building is another constraint.



Fig.11 Two buildings of our university were selected as the targets for students practicing projection mapping. (a) building of No. 27 and (b) KIT radio broadcast station

Students' practicing activities included measuring the building, designing content, testing equipment, creating the content, and doing final performance. At each stage, safety was educated and ensured. We have encouraged students to design contents based on their original ideas. Around a topic, each student may propose one original idea depending on his/her own developing ability to ensure there are positively involved in the learning and creating activities.

In 2014, our students created an original content of 18 minutes long for projection mapping on the building of No. 27. During *Kodaisai 2014, the annual festivals of Kanazawa Institute of Technology*, they demonstrated their learning results successfully and shared enjoyment with many people taking part in the events ²³⁾. As shown in Fig.12, the rind style modelling and block based modelling were applied in the projection mapping.

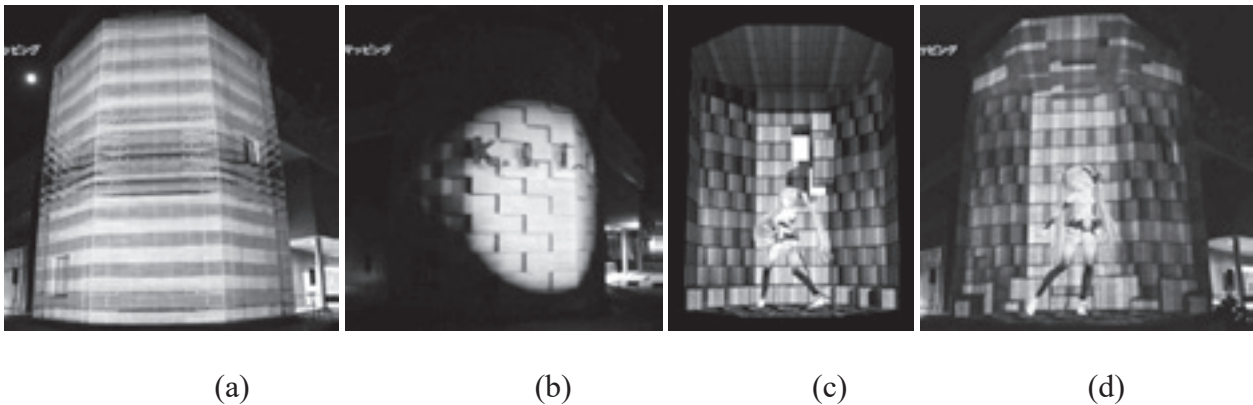


Fig.12 Projection mapping on building No.27, (a) by rind style modelling, (b) by block based modelling, (c) and (d) showing a 3D virtual hall, and a 3D character Miku singing and dancing inside the hall. (c) an animation of blocks exchanging locations, (d) blocks on the hall floor jumping upward as if they were dancing too.

During 2015 annual festivals, students demonstrated projection mapping on the building of radio broadcast, using the presented both modelling methods. Behind the glass wall, there was actually a big hall of open space. But in creating projection contents, we supposed there was a virtual room with walls, ceiling and floor, as shown in Fig.13-(b). Each wall is represented as block based modelling. For showing font message of "IDEALS" (Fig.14), we integrated texture mapping with block based model, enabling every block to rotate 180 degrees so as to show images attached to its opposite side. When the cube is rotated, the two-dimensional image appears gradually and eventually appears as a whole.



Fig.13 projection mapping on the building of radio broadcast, using ring style (a) and block based (b) modelling methods

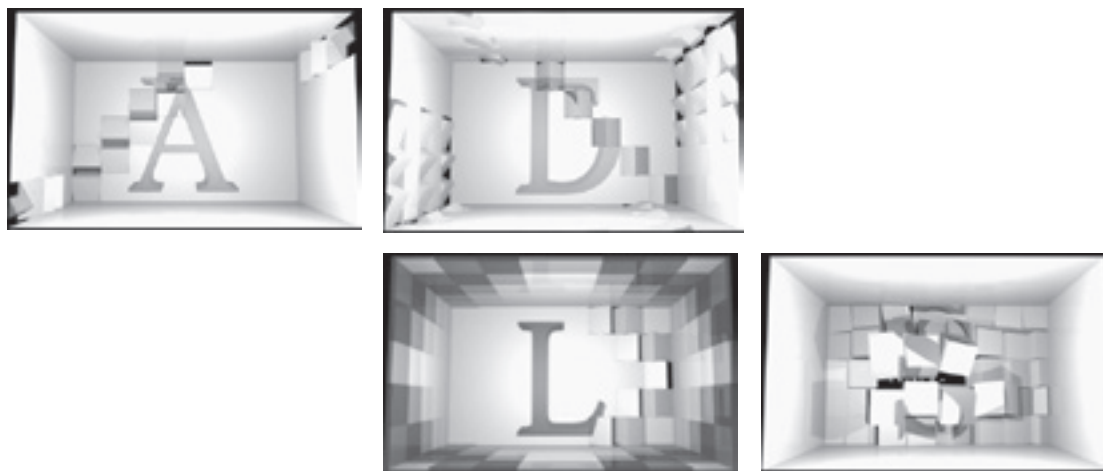


Fig.14 Integrate block based modelling with texture mapping to show images

In 2016 we returned to the octagonal building of No.27 and did an interactive projection mapping of 3D Tetris game. We applied block based modelling to expand the original 2D game to 3D. As shown in Fig.15, a cross-arrangement of cube and space reflected the features of original 2D Tetris game very well, and meantime, marching the building structure the best. In order to highlight the characteristics of the building, the cubes at the eight corners used a different color for the cubes of the building.

5. Conclusions

From 2014 to 2016, 30 students, two of them were graduate students and the others were seniors, took part in our projection mapping education program. Feedbacks from annual student survey show they were satisfied with this program. Their activities have proved the presented modelling methods are effective, and our educational materials are easy to learn. Most students fully grasped the basic knowledges and skills of projection mapping. Some even made many extensions to the presented methods. We always expect that students are not only taught existing knowledge and skills, but also inspired to create new ones.

Students mentioned that team building was an excellent experience. During the education program, we emphasized the importance of cooperation with others. Graduate students were patient and kind to the under-graduates, and the under-graduates paid respect to graduate students. Graduate students and seniors played a key role in design and creation of the content.

In spite of being busy they spent a lot of time on teaching the lower-year students about computer graphics and using software.



Fig.15 Interactive projection mapping on the building of No.27, using block based modelling to construct 3D Tetris game.

In replying to our question in the survey: what do you find unsatisfied, many senior students have given their desires to upgrade ability. They hoped to be more capable of solving problems and making decisions, as the graduate students demonstrated. As teachers we perceive the difference of students, and know each's strengths and weaknesses. We will provide more opportunities for them to improve their problem solving and decision making abilities. Meantime, we need to add more specific description into our educational materials²⁴⁾. Because we used only sphere and plane as examples, some students feel difficult to apply to buildings of complex structures. One solution is to prepare more examples of primitive formations, such as cylinder, cone, pyramid, and so on. Learning more primitive knowledge, students would be more confident to deal with complex targets.

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