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The Construction of a Rideable Geometric Object Based on a Conical Form: Regarding "Space Walk on the Earth" With Ellipsoidal Rolling Plane

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Abstract. Under the theme "art object rolling smoothly on the floor" the author has thus far created large moving objects using stainless steel pipes from a sculptural perspective. Thus a series of objects has been designed wherein a participatory audience can feel the movement and changes in forms by directly touching the objects with their hands and using their bodies. In this study, the author has constructed a hands-on solid geometric object with an ellipsoidal rolling plane based on conical form. This art form is one that people can sit on, balance, and roll on the ground by providing the driving power to roll it.

Key Words: Formative theory, form composition, kinetic art

MSC 2010: 00A66, 51N05

1. Introduction

There are well-known examples of objects created by focusing on the fact that both roll in a consistent directional manner on planes in three-dimensional space, the *"Two-Circle-Roller"* (Fig. 1) and the *"Sphericon"* (Fig. 2) [2, 3]. The *Two-Circle-Roller* is a special case of the *"Oloid"* invented by Paul Schatz (1898–1979) that consists of two mutually intruding perfect circular discs in orthogonal planes [7, 1]. The *Sphericon* was invented by Colin Roberts 1970. These objects roll on planes while moving. The height of their centers of gravity remains unchanged (Figs. 3 and 4).

2. Background of study

2.1. Object upsizing using stainless steel pipes

Based on the two structures mentioned above, the author used stainless steel pipes to develop large objects at which viewers can feel the movement and changes in forms by touching with

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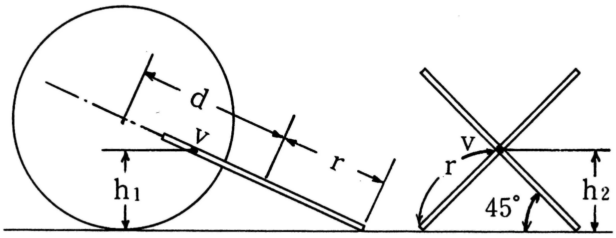

Figure 1: Structure of *“Two-Circle-Roller”*

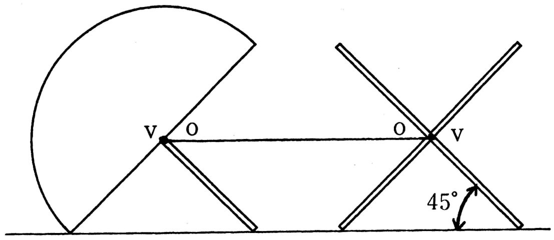

Figure 2: Structure of *“Sphericon”*

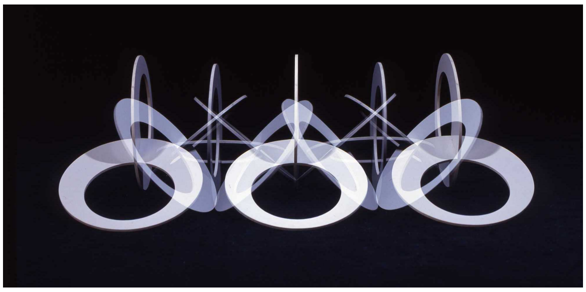

Figure 3: Movement of *“Two-Circle-Roller”*

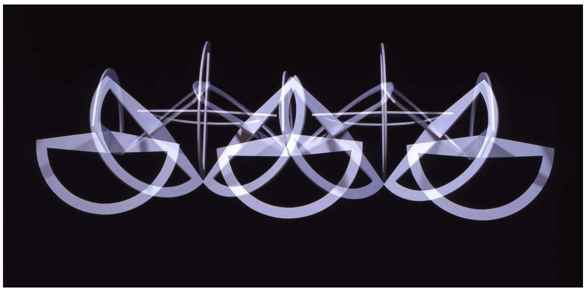

Figure 4: Movement of *“Sphericon”*

their hands. These objects are described in a series called *“A study of tangible”* presented in an earlier study conducted in 2006 [4].

In recent years, the author has also created the variations of *“A study of tangible”*, such as *“A study of tangible – E”* (Figs. 5 and 6) and *“A study of tangible – K”* (Figs. 7 and 8), in which perfect circles are replaced by ellipses in those structures [5, 6]. These objects create new visual impressions.

2.2. *“A Study of Tangible – Zero”* and its prototype

Aside from the *“Two-Circle-Roller”* and *“Sphericon”*, there are other forms that roll smoothly. One example would be a right circular cone that can roll smoothly with its apex point acting as a supporting point and its bottom as a rolling plane.

Here, consider the case where a cross section created by cutting the cone diagonally with respect to its center axis (i.e., an ellipse) acts as a rolling plane. In this case, the rolling behavior of the object fluctuates, that is, the simple rolling movement of the right circular cone changes to movement with significant changes in the object’s height.

Accordingly, we created a prototype *“A study of tangible – Zero”* (Figs. 9 and 10) in which the ellipse created by cutting the cone (with an apex angle of 105°) at an angle of 75° with respect to its center axis acts as a rolling plane (Fig. 9). As can be seen in Fig. 7, the ellipsoidal rolling plane provides an up-and-down movement like a large wave.

Figure 11 shows a large-sized *“A study of tangible – Zero”* created by using a stainless steel pipe. According to the calculation, the object can roll smoothly when its center of gravity is on the center axis of the cone. In this design, however, the center of gravity cannot be aligned with the cone’s center axis by adjusting the form alone due to a material restriction (constant pipe diameter). For this reason, it was necessary to put a counterweight in the pipe.

Figure 5: Variations of *"Oloid"*
"A study of tangible – E"

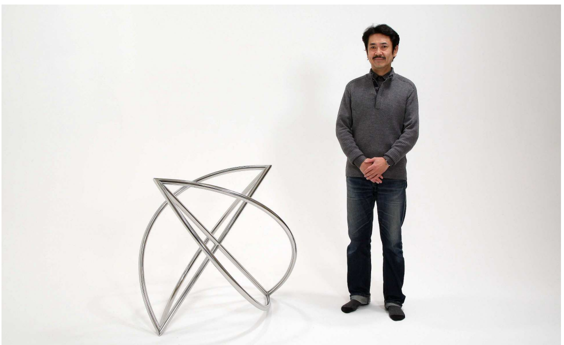

Figure 6: Variations of *"Sphericon"*
"A study of tangible – K"

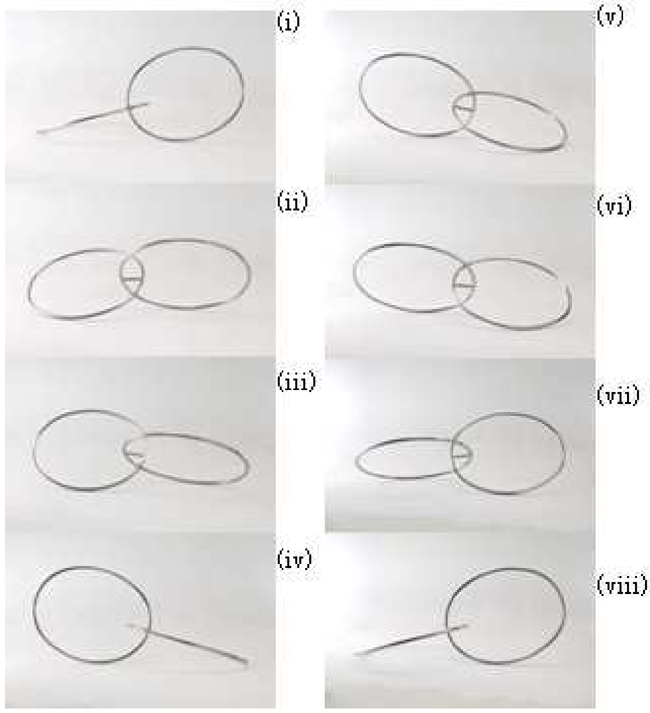

Figure 7: Movement of the front view
"A study of tangible – E" ((i) to (viii))

3. Creation process of *"Space Walk on the Earth"*

3.1. Concept of basic structure

The author originally created a series of large stainless pipe objects, with a view toward further evolving hands-on objects that people can sit on and feel the gravity and movement.

This study was conducted to solve "misalignment of the center of gravity with the center axis," a high-priority issue remaining in *"A study of tangible – Zero"*, by applying the previously suggested concept of "people sitting on objects."

Based on certain ideas, examinations using sketches, simplified (two-dimensional) drawings, study models, and scale models were repeated, resulting in a design initiated according to the following basic guidelines:

1) Basic structure: Cone with apex angle of 105 and rolling plane (ellipse) created by cutting the cone at 75 with respect to its center axis (like *"A study of tangible – Zero"*)
2) Users: Typical adult males, weighing 60 to 75 kg and standing 165 to 175 cm tall (people who can secure safety by themselves)
3) How to sit on: Sit on from the inner side of the ring, step on the support section, and then support one's own weight. (This is because, although the posture where users lay on their stomachs was initially considered, it was determined that users have difficulty controlling the object by shifting their own weight.)

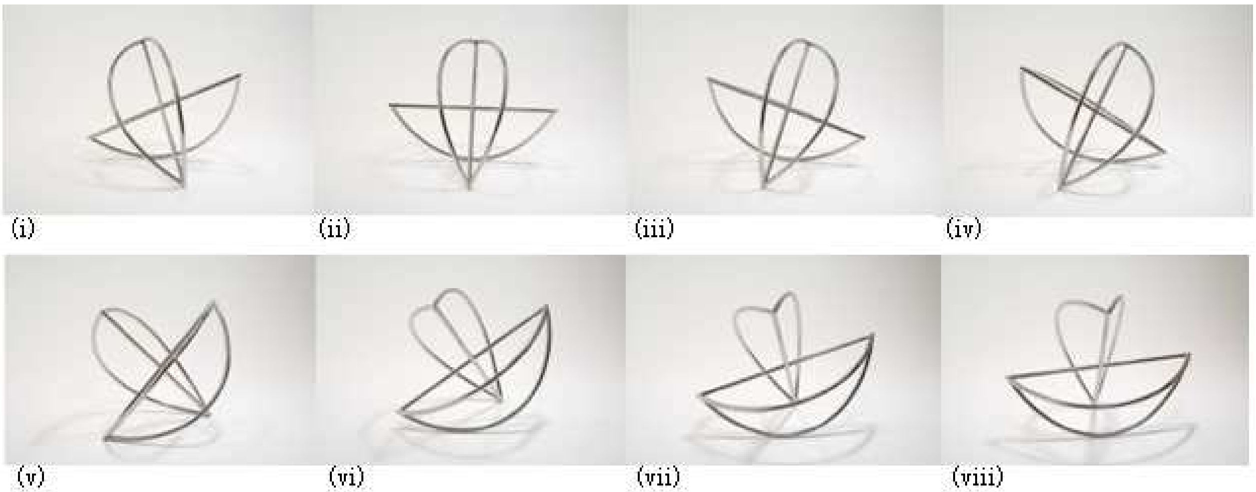

Figure 8: Movement of the side view *“A study of tangible – K”* ((i) to (viii))

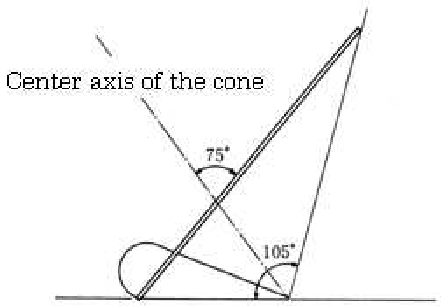

Figure 9: Structure of a prototype
“A study of tangible – Zero”

Figure 10: Movement of a prototype
“A study of tangible – Zero”

4) Weight: No more than double the user’s weight under the condition of secured structural safety. (Total weight exceeding 150 kg was expected to significantly affect the control of rolling movement.)
5) Size: Maximum size that satisfies requirements 1) to 4)

3.2. Determination of basic structure and calculation of object size

To begin with, the dimensions were calculated from the original scale drawing based on requirements 1) to 5). Fig. 12 shows the CAD drawing used for calculation.

If the cone with an apex angle of 105 is cut at 75 with respect to its center axis, namely at 15 with respect to its bottom, the cut end surface becomes an ellipse with the minor/major axis ratio 1000 : 1105.

Accordingly, the dimensions allowing sitting on by adults with some margin are expected to be those calculated from the major axis ranging from 1700 to 2500 mm. Then some values were substituted in the calculation to compare object sizes.

For example, when the major axis is set to 1700 mm in this structure, the minor axis becomes 1538.7 mm, resulting in a size too small for adults. In contrast, when calculated with a major axis set to 2500 mm, the minor axis becomes 2262 mm. Although these dimensions are spacious enough for a user to sit on, the object weighs about 100 kg. Therefore, severe

Figure 11: *"A study of tangible – Zero"*

difficulty in handling the object was expected.

In this way, various conditions were examined and calculations performed to reduce the weight, while securing the pipe diameter required for the structure. As a result, it was determined to use the ellipse with a major axis of 2350 mm and minor axis of 2127 mm.

3.3. Four-view drawing for creation use and position of the center of gravity

For creating the object described in this study, the center of gravity could not be aligned with the cone's center axis by adjusting the form alone in a single ellipse structure due to a material restriction (using a pipe with a constant diameter) like in the previous object (Fig. 11).

Furthermore, to allow users to sit on, it is necessary to create a "seat" section where users can support body weights mainly by using their waists. For this reason, a "triple ring" structure that can be regarded a sculptural design element was utilized for this object.

Figure 9 shows the finalized CAD drawing for creating the object. By decentering the two inner rings of the triple rings toward the supporting point, the center of gravity (marked with a star) was moved as much as possible to the center axis side within the range in which users can sit on.

3.4. Sketch of finished object and structural details

Figure 14 is a sketch of the finished object created using CAD. As mentioned in Section 3.2, one adult person can sit on this object, and change of the center of gravity by intentionally shifting the body weight to become the driving power for rolling. Therefore, it is necessary to reduce the object's weight as much as possible. To achieve this, three types of pipes with diameters of 48.6 mm, 42.7 mm and 38.0 mm were used for the outer, middle and inner ellipses, respectively.

In considering the strength requirements and beauty of a simple design, a pipe with a diameter of 34.0 mm — the smallest among the four pipe diameters — is used for straight parts that hold the three ellipses in a coplanar manner. The mounting angle is about 51.5°

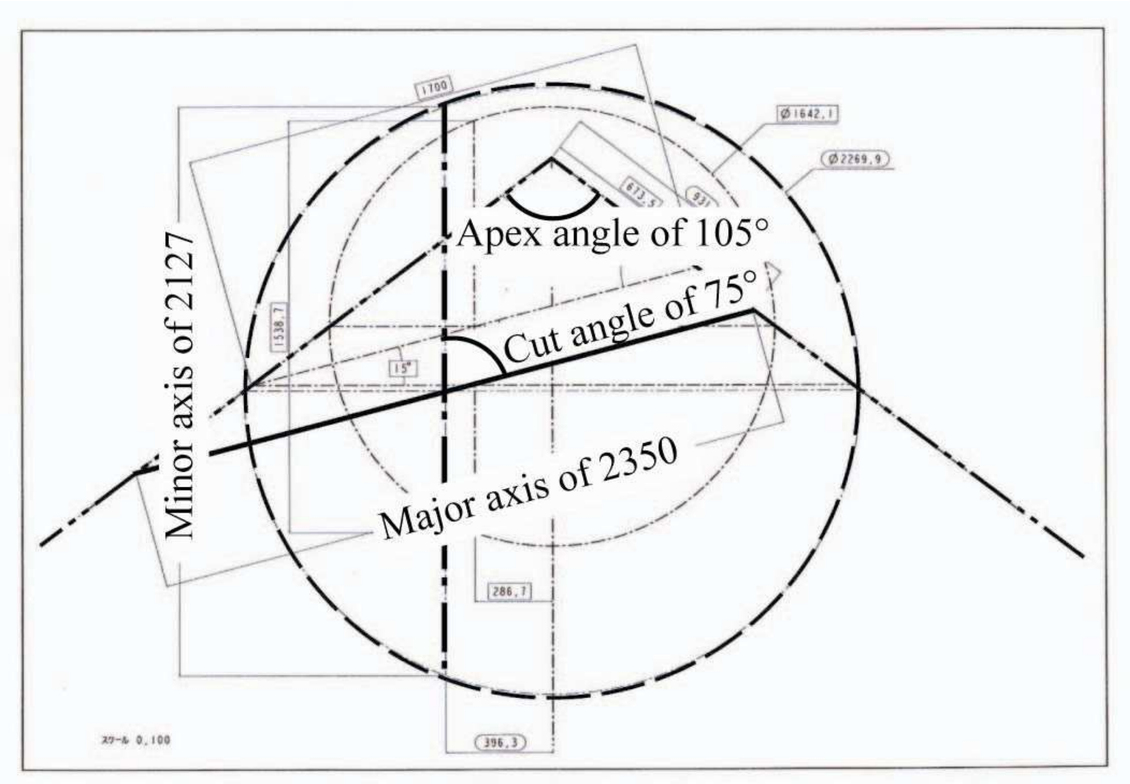

Figure 12: Calculation drawing of *“Space Walk on the Earth”*

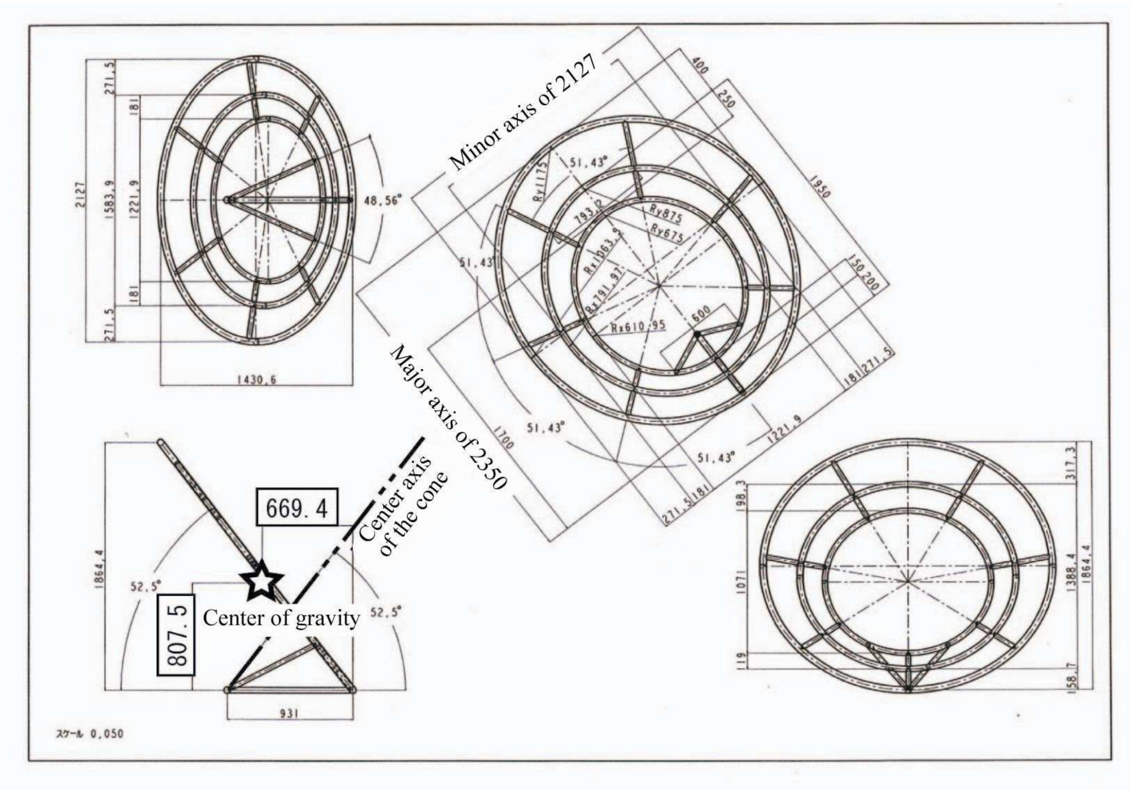

Figure 13: Four-view drawing of *“Space Walk on the Earth”*

when measured at the center of the innermost ellipse, which is derived by dividing the ellipse perimeter equally into seven sections.

At the supporting point, a sphere with a diameter of 50 mm is used so that the weight is not applied to extremely narrow areas such as a point.

Since no "footrest" was provided for the initial use of the object, users found it difficult to support their body balance. Thus, a "footrest" bar (not shown in the drawing) was installed between the two pipes connected to the innermost ellipse. These two pipes are among the three pipes extending from the sphere at the supporting point of the object to the ellipse. This footrest allows users to sit on the object stably.

In this finalized design, the calculated object weight slightly exceeds 67 kg. With this weight, users are not expected to feel much difficulty in terms of transport, installation or control.

4. Finished *"Space Walk on the Earth"*

Figures 15 and 16 show the large object created on the base of Figs. 8 to 10. Since the prerequisite for this object is that users touch various sections of the object and roll it with their feet on the footrest, a hairline finish was given to the stainless steel surface so that dirt does not become conspicuous.

Compared with the previous object *"A study of tangible – Zero"* shown in Fig. 11, the size of the object created in this study is 1.5 times larger so that it rolls more slowly and looks grand. Moreover, since the major axis is as long as 2350 mm (compared to 1400 mm for the previous object), the maximum height when the object stands diagonally with the triangular pyramid on the ground is 1850 mm. This is higher than the average height of Japanese adult males, providing a great presence even when the object is stationary.

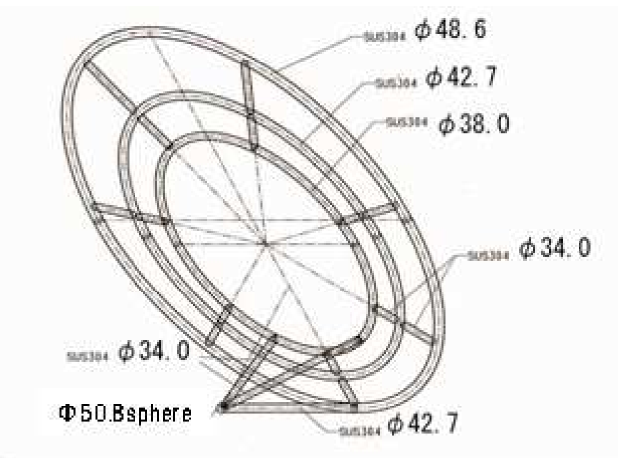

Figure 14: Sketch of finished *"Space Walk on the Earth"*

Figure 15: Finished *"Space Walk on the Earth"*

Figure 16: Sitting condition of *“Space Walk on the Earth”*

5. Movement of *“Space Walk on the Earth”* and discussion

In Fig. 17, (i) to (ix) are successive photographs showing the object actually being rolled by a user. The user can roll the object smoothly by simply shifting the body weight and can also change speed. Furthermore, the object can be rolled in the opposite direction by the user shifting the body weight to the opposite side. However, freely controlling the object is difficult for users lacking a certain level of muscle strength (relative to back, abdominal, and upper arm muscles).

Figure 17 shows trial use on the relatively soft ground of an athletic park. During this use, it was confirmed that the object gradually changes its standing directions during up-and-down movement like a large wave centered on the supporting point. Moreover, smoother rolling, stopping, and reverse rolling can be expected by using the object on a hard floor (such as a floor of plastic tiles).

6. Conclusion

From the study mentioned above, the following results were obtained.

1) Misalignment of the center of gravity with the center axis, which had been a problem at past objects, was solved by a balance control performed by users sitting on the object.
2) By shifting their body weight, users were able to roll and stop the object, and roll it in the opposite direction by themselves.
3) It was found that even when using a large object with total weight exceeding 100 kg on soft level ground, the object having unchanged height at the center of gravity could roll without any stopping.
4) It was confirmed that by reducing its size and weight, this object could be evolved into play equipment available for elementary school (high grades) to junior high school students.

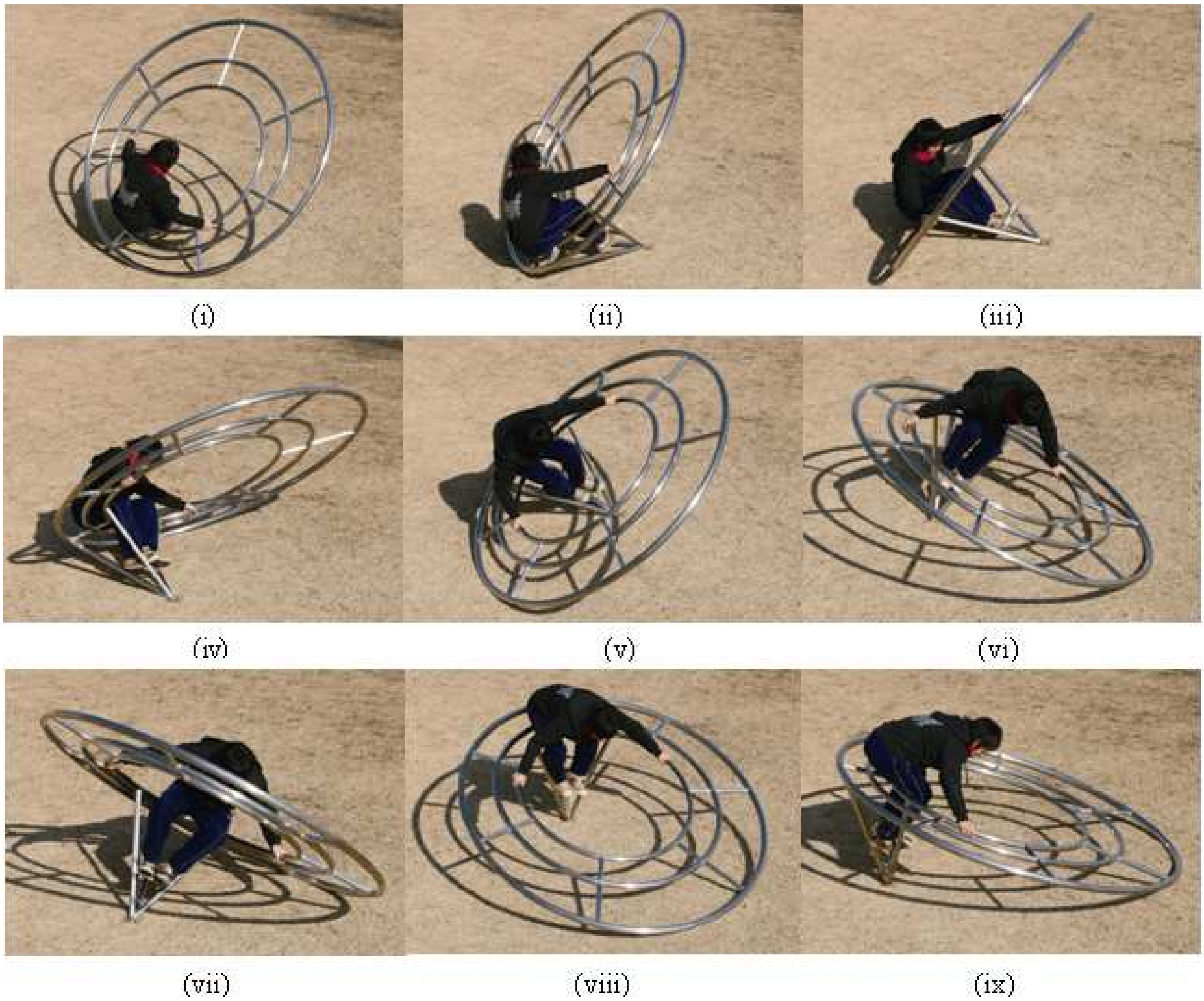

Figure 17: Movement of *“Space Walk on the Earth”* ((i) to (ix))

7. After — future work and issues

The author has created objects with sculptural and scientific features that deepen the understanding of basic characteristics of various forms and such invisible things like “space,” “time” and “gravity.” In the future, the author will suggest large educational play equipment of which infants to adults can intuitively feel the important physical characteristics, not only from sculptural and graphic science perspectives, but also from the perspectives of science/mathematics, health and physical education by sitting on and playing with such equipment.

In such work, consideration of safety will be a particular issue. Moving objects weighing more than 50 kg are dangerous for young children not being supervised by their parents. The object created in this study is planned to be exhibited on a hard floor in the near future, and viewer opinions about hands-on objects (that users can sit on and play with) will be directly collected. The author will refer to such opinions when creating lightweight, figurative objects free of structural problems and having play equipment characteristics.

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