Visual Media Culture Supported by Human Depth Illusion

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Abstract There is great difference between the real world and its images; the real world is three-dimensional whereas the images are two-dimensional. In spite of this difference we can enjoy visual media without any special efforts. Why can we do this ? This question can be partly answered by the study of depth illusion. It seems that the human brains try to recover the depth from images using strong performances for some special subclass of objects such as rectangular solids. This observation also suggests fragility of the visual media culture. We discuss this point using optical illusion raised by impossible objects and impossible motions.

Keywords: Depth perception, impossible object, impossible motion, optical illusion, visual media

1 Introduction

We see objects in the real world by two eyes, by which we can recognize the distances to the objects. This is based on a mathematical fact that each point on an object can be located in the three-dimensional space as the point of intersection of two rays of sight from our eyes to the target point. This visual function is called the binocular stereo [1, 3, 4].

When we see images such as photographs and movies, on the other hand, the visual data include information obtained through only one eye, because a camera has only a single lens center. There is no explicit information about the distance to the objects. Nevertheless, we usually perceive depth to the objects in the images. This visual function is sometimes called the monocular stereo [1, 7].

Of course we can see the images by our two eyes, but this gives just the distance to the images, but not to the objects contained in the images.

Nowadays we are surrounded by various visual media, and we are apt to forget the differences between seeing objects directly and seeing them through images. However, there is a great difference between the binocular stereo and the monocular stereo. The former is based on the mathematical principle, while the latter is not.

The monocular stereo is based on just guessing the depths, and consequently very fragile. We will see this fragility through depth illusion raised by impossible objects and impossible motions.

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2 Degrees of Freedom in Object Reconstruction

If we are given an object, the viewpoint E and the image plane I, the image of the object projected on the image plane with respect to the center of projection at E is uniquely determined. However, even if we are given E, I and the image, the original object is not unique. There is freedom in the reconstruction of the object from the image. This freedom can be mathematically specified in the following way [6].

We assume that the object is a polyhedron, that is, an object bounded by planar faces. Suppose that the viewpoint E is at the origin of the (x, y, z) coordinate system, and that the image is fixed on the plane $z = 1$. Assume that the object in the image contains n vertices and m faces. Let ${v_i}' = (x_i, y_i, 1)$ be the i-th vertex on the image. The original counterpart v_i of this vertex should be on the ray of sight emanating at the origin and passing through ${v_i}'$. Hence, the original vertex can be expressed by $v_i = (x_i/t_i, y_i/t_i, 1/t_i)$ where t_i is an unknown variable.

Let f_j be the plane containing the j-th face of the object, and let

$$a_j x + b_j y + c_j z + 1 = 0 \tag{1}$$

be the equation of f_j, where a_j, b_j and c_j are unknown variables.

Suppose that the vertex v_i should be on the face f_j. Then we can substitute the coordinates of v_i into eq. (1), and get

$$a_j x_i + b_j y_i + c_j + t_i = 0. \tag{2}$$

This is linear in the unknowns t_i, a_j, b_j and c_j.

For each pair of a vertex and a face containing it, we get the equation similar to eq. (2), and hence we get a system of linear equations, which we denote by

$$A\boldsymbol{w} = 0, \tag{3}$$

where $\boldsymbol{w} = {}^{\mathrm{t}}(t_1, \ldots, t_n, a_1, b_1, c_1, \ldots, a_m, b_m, c_m)$ is a vector of unknown variables and A is a constant matrix.

This system of equation contains $n + 3m$ unknown variables, and hence there are

$$n + 3m - \mathrm{rank}(A) \tag{4}$$

degrees of freedom in the choice of the object from the image.

3 Depth Illusion

The degrees of freedom specified by eq. (4) are at least 4 for a thick object. This freedom enables us to design unfamiliar objects that look familiar, and thus raise various optical illusion [6]. The followings are examples of such illusions.

3.1 Impossible objects

There is a class of pictures called "pictures of impossible objects" [5, 13]. This class of pictures gives us an impression of three-dimensional structure but at the same time give us an impression of impossibility. An example is the picture of endless loop of stairs shown in Fig. 1 which is famous in that it is used by Dutch artist M. C. Escher in his artwork "Ascending and Descending" (1960) [2].

(a) (b) (c)

Figure 1: Impossible object “Endless Loop of Stairs”: (a) picture; (b) solid realizing the picture (a); (c) another view of the solid.

The impression of impossibility seems to come from our knowledge that stairs consist of horizontal and vertical plates. However, the freedom specified in eq. (4) suggest that there are other objects, and actually we can construct a three-dimensional solid whose projection coincides with the picture. Fig. 1(b) shows an example of a solid that looks the same as Fig. 1(a) and Fig. 1(c) is another view of the same solid.

Another example is given in Fig. 2, where (a) shows a “picture of an impossible object”, (b) shows a solid, and (c) shows an another view of the solid.

(a) (b) (c)

Figure 2: Impossible objects “Two L’s”: (a) picture; (b) solid realizing the picture (a); (c) another view of the solid.

These examples show that pictures of impossible objects are not necessarily impossible; some of them are realizable as actual three-dimensional solids. This phenomenon shows that the human brains sometimes cannot extract solids represented in the images.

3.2 Impossible motions

The freedom in the choice of objects represented in images also enables us to design solids that look ordinary, but motions inserted to the solids appear to be physically impossible [10].

An example is shown in Fig. 3. The image (a) appears to be a solid consisting of four slopes slanted down to the four directions from the highest center. However, if we place balls on any slopes, they roll toward the center as if they are defying the gravity. Actually the center is the lowest as shown in (b), and the balls just roll downhill obeying the gravity law [8].

(a) (b)

Figure 3: Impossible motion “Magnet-Like Slopes”: (a) slopes on which balls appear to be rolling uphill; (b) another view of the same solid.

Another example is shown in Fig. 4. As shown in (a), the solid consists of a pole and four perches which look horizontal and crossing in right angles. However, a flat ring hangs in such a way that it passes behind the pole but in front of all the four perches. The actual shape of the solid is as shown in (b); the four perches all extend toward behind the pole [9].

One interesting observation is that the impossible motions are perceived even if we are told the true shapes of the objects. This fact implies that the impossible motion illusion cannot be removed even if we know the truth.

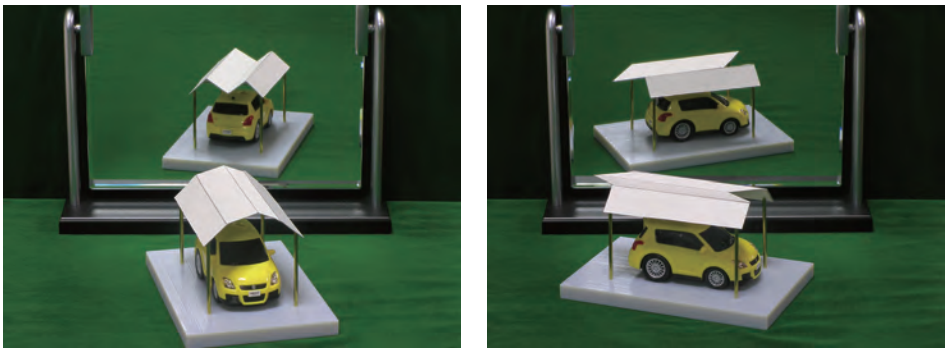
(a) (b)

Figure 4: Impossible motion “Four Perches and a Ring”: (a) ring hanging the perches in a strange way; (b) another view of the same solid.

3.3 Ambiguous cylinders

The third class of depth illusion is ambiguous cylinders, whose appearances change drastically when they are reflected in a mirror [11, 12]. An example is shown in Fig. 5(a). The roof of the garage appears to be round when it is seen directly, while it appears to be corrugated in a mirror. Fig. 5(b) shows the same solid seen from another angle. From this image, we can understand that the true shape of the roof is neither of the appearances.

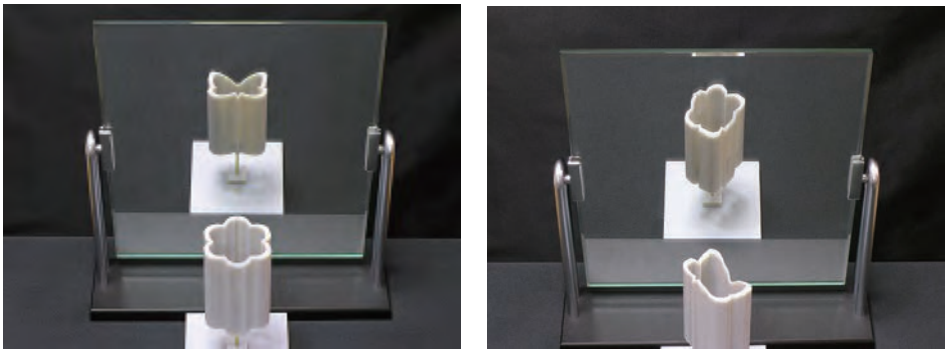
Another example is given in Fig. 6. As seen in (a), the object appears to be a cylinder whose section



(a) (b)

Figure 5: Ambiguous cylinder “Ambiguous Garage Roof”: (a) solid and its mirror image seen from a special viewpoint; (b) the same solid seen from a general viewpoint.

is a flower shape, while its mirror image is a butterfly shape. Fig. 6(b) is another view of the same cylinder.



(a) (b)

Figure 6: Ambiguous cylinder “Flower and Butterfly”: (a) solid and its mirror image seen from a special viewpoint; (b) the same solid seen from a general viewpoint.

Both of the objects are made as the surfaces swept by a line segment which moves in a space without changing the orientation. Let us call this type of surface as a cylindrical surface; the solid in Fig. 6 is a closed cylinder while the garage roof in Fig. 5 is an open cylinder. The length of the cylinder measured along the axis direction (i.e., the direction of the sweeping line segment) is the same at every point on the surface. The human brains seem to interpret the edge of the cylinder as the intersection of the cylinder and a plane perpendicular to the axis of the cylinder. This causes the ambiguous cylinder illusion.

Ambiguous cylinder can be made because of the freedom in the reconstruction of objects. Actually this freedom enables us to design solids whose projections onto two prespecified directions give desired pair of two-dimensional shapes [11].

4 Fragility of Visual Media

Depth illusions we have observed suggest that it is difficult to interpret images as three-dimensional objects. However, it seems that visual media in our daily lives such as photographs, television, movies and other videos are used on the assumption that the humans can perceive correct depths from those media. Therefore, we have to be careful about this gap.

It seems that visual media are created mainly for generating reality, but we can intentionally create visual media that give incorrect impression of the real world.

One common example is photographs used in the advertisement of real estates. Photographs attached in house advertisements usually give us impression that the rooms appear to be larger than the actual sizes. We might say this is also an illusion. However, this illusion is not serious in that what is different from reality is just an impression of the space size.

On the other hand, the optical illusions presented in Section 3 are more extreme, because the perceived shapes of objects are quite different from the real objects. For example, slopes are perceived opposite in "Magnet-Like Slopes", and the appearances change in a mirror completely for ambiguous cylinders. These depth illusions suggest that visual media such as photographs and movies contain serious risk in communicating about shapes of objects. In particular this implies the following two risks.

First, we are apt to think that there is not so much difference between seeing objects directly and seeing them through images. However, there is great difference; the former is the binocular stereo while the latter is the monocular stereo. Therefore, shape information might be distorted through visual media even if it is not intentional.

Second and more seriously, visual media can be used to distort shape data intentionally, as we have seem in various types of depth illusions in Section 3. We can intentionally make viewers to perceive the orientations of slopes opposite to actual slopes, as we have seen in impossible motion illusion. We can also make two viewers who see objects from different viewpoints to perceive the same object as quite different from each other.

Creatures got a pair of eyes in the middle of Cambrian period, which is about 500 million years ago. Since then the stereo vision functions in our brains evolved in sufficiently long time. On the other hand, the visual media technology such as photographs and movies began only several hundreds years ago. This implies that if we shrink the time so that we got a pair of eyes one year ago, we got visual media technology only 30 second ago. Therefore, we have not yet experienced the visual media technology to evolve the monocular stereo function.

The serious illusions in depth perception through images might be the result of insufficient time to evolve the monocular stereo. So we have to be careful about this aspect of visual media technology.

5 Concluding Remarks

We have shown depth illusion phenomena such as impossible objects, impossible motions and ambiguous cylinders. They all suggest that the monocular stereo function in our brains is fragile, and sometimes makes serious mistakes in perceiving depth to the object surfaces and consequently the shapes of the objects. This might be due to the rapid development of visual media technology, which is too short for our brains to evolve the visual data processing for the monocular stereo.

We have to recognize this shortcoming of the visual media technology, and to be careful in avoiding errors in depth perception.

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