Partial Sphere Container as Chinese Pan with Convex Bottom for Vertual Cooking System

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***Abstract*—We have proposed a manipulation model of a group of individual bodies (GIB) for our virtual cooking system. The GIB represents a mass of small solid bodies (such as rice and sand) and it is treated as one object in a container with flat bottom in the model. In this paper, we enable to use a Chinese pan that shape is partial sphere. The shape of the GIB has been represented as a height field, and the shape of the container is also represented as a height field in our new model. The purpose of our GIB manipulation model is to be applied for home use virtual reality systems. Therefore interactive simulation process is more necessary than exact behavior.**

***Index Terms*—a group of individual bodies, virtual cooking system, interactive manipulation, convex container**

I. Introduction

Virtual Reality (VR) technology has spread through out various fields such as education, industry and medical fields recently. Moreover, many simulators [1][2][3] have been developed. However, VR system is not commercially popular.

Therefore, we have developed virtual cooking learning system for home use. Cooking is an act which needs practice by repetition in spite of its labor. In addition, it is risky for beginners to cut and heat food. As one of virtual systems for leaning cooking, an cooking simulator using a frying pan [4] have been developed. By using the simulator, users can obtain visual information of virtual ingredients about physical and chemical reaction state during cooking process. The ingredients in the system are assumed as rigid bodies such as a slice of meat, vegetables and so on.

We think that ingredient is often a mass of small pieces such as rice. We proposed a manipulation model of a group of individual bodies (GIB) for our virtual cooking system [5][6]. The model represents a lot of small bodies (such as rice and pieces of ingredients) behavior, and the GIB is treated as one object in a container for interactive manipulation. Some researches to simulate behavior of many small bodies have been developed. Lava behavior models [7][8] represent flowing down lava calculated with a particle method. A sand behavior model [9] represents sand collapse with Height Span Map over adjacent grids. However, these models need a lot of time to calculate. They cannot be applied for an interactive system or cannot treat objects moving fast. Our goal is an interactive system for home use. It is necessary for our system to calculate GIB behavior quickly. The model we have proposed uses simplified methods to represent movement of a GIB and render the shape of it for reducing complexity.

In our pilot system, the shape of a container was assumed as a short cylinder with a flat bottom like a frying pan. We think there is curved bottom container like a Chinese pan. It has a convex bottom, which is almost similar to a partial sphere. In this paper, we enable to use a Chinese pan which is partial sphere. The shape of a GIB has been represented with a height field. Transition of heights over adjacent grids represents the movement of a GIB. In our new model, the shape of the container is also represented with a height field, and the GIB movement on a convex bottom of a container is considered once more. The new model can represent plausible behavior of a GIB on both of flat and convex bottom containers.

Section 2 explains the manipulation models of a GIB we have proposed. In section 3 the model using partial sphere container is explained. Section 4 presents experiments with our virtual cooking system based on the model using partial sphere container. Finally, Section 5 concludes this paper.

II. Manipulation Model of GIB

A. GIB on cylinder container

1) Representation of GIB: In our manipulation model of a GIB, the shape of the container was assumed as a short cylinder with a flat bottom and vertical sides. A GIB on a cylinder container is represented with a height field which is defined on the bottom of the container (Fig. 1). The GIB receives constant forces from gravity, friction from the bottom and reaction force from a side. The shape of the GIB is represented as its volume. The volume of a part of GIB on the grid (x_i, y_j) is defined as $f(x_i, y_j)$, which is calculated with the height $h(x_i, y_j)$ of the GIB on the grid and the square measure of the grid. The GIB volume V on the container C is calculated as below.

$$V = \sum_{(x_i, y_j)\in C} f(x_i, y_j). \tag{1}$$

2) Transformation of GIB on cylinder container: We represent a plausible GIB transformation using a curved surface which is called Transformation Surface (TS). When a GIB exists in the center of a container, for example (Fig.2-1), it is expected to slide down to the lower part. Thus, a TS is applied around the GIB (Fig. 2-2). As a result the GIB moves (Fig. 2-3).

In fact, it is difficult to calculate the TS shape because a GIB behavior is complex. Thus, we use an alternative process. We think a GIB on the flat bottom receives constant forces from gravity, friction and reaction force from the container. Therefore, we use a TS of a half of elliptic cylinder shape to simplify calculation (Fig. 3). Parameters of the TS are defined as below (Fig. 4). The size of the TS is defined with the semi major axis of elliptic a and the semi minor axis b. The place and the direction of the TS depend on the center of TS o_D and the center axis L_D. The length of a is calculated with the volume of the GIB V and reaction force from the side $\mathbf{F_n}$. The length of b is calculated from V, the appropriate force that the GIB is received $\mathbf{F_b}$, a static friction force from the bottom μ, and a dynamic one μ'. The coordinate of o_D is determined from a, the center of the GIB $\mathbf{G_c}$, and the direction of $\mathbf{F_b}$. These parameters are calculated as below.

$$a = \left(\begin{array}{rl} T_1 - \mid \mathbf{F_n} \mid & (T_1 \geq \mid \mathbf{F_n} \mid) \\ 0 & (T_1 < \mid \mathbf{F_n} \mid) \end{array} \right. . \tag{2}$$

$$b = \left(\begin{array}{rl} (\mid \mathbf{F_b} \mid - \mu')T_2\sqrt{V} & (\mid \mathbf{F_b} \mid \geq \mu) \\ 0 & (\mid \mathbf{F_b} \mid < \mu) \end{array} \right. . \tag{3}$$

$$\mathbf{o_D} = \mathbf{G_c} + \frac{\mathbf{F_b}}{\mid \mathbf{F_b} \mid} a. \tag{4}$$

The TS can represented a difference of properties of the GIB such as viscosity by changing constants T_1, T_2. The axis L_D is perpendicular to the direction of $\mathbf{F_b}$, passing on o_D. The length of r_D is appropriate constant which is longer than the radius of container bottom.

With the TS, a GIB on a tilted container change its shape to represent moving (Fig. 5). To increase volume of GIB at lower part, a half of elliptic cylinder TS is applied at the appropriate place (Fig. 5-2). Then the volume of the TS is added to one of the GIB (Fig.5-3). After that, volume of the GIB is corrected (Fig. 5-4). Finally, the GIB finishes moving.

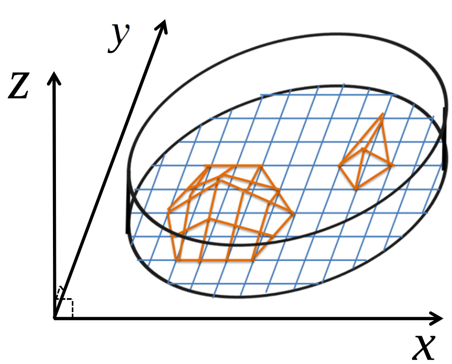

Fig. 1. GIB represented with height field

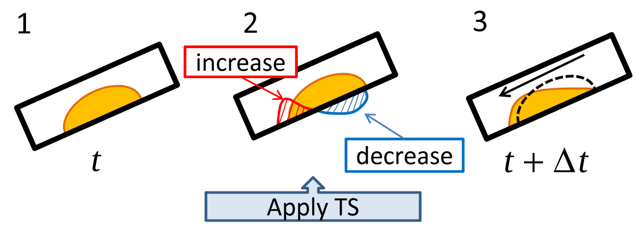

Fig. 2. Vertical section of GIB in cylinder container

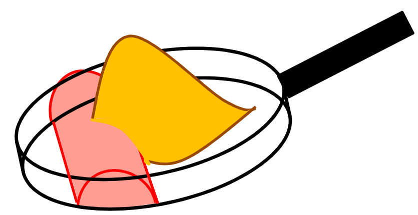

Fig. 3. TS applied on cylinder container

B. Fall of GIB

We have considered some different situations, and proposed various manipulation models of a GIB. The model explained in the section II-A describes the GIB which exists only on a container. We have also developed the model of a GIB falling out of a container (Fig. 6). To improve reality, we express rough feel of the surface of a GIB. We render it with not only texture mapping but also particles over the texture mapped surface. A particle is assumed to contain some ingredients. The existence of particles is decided at random based on existence probability. And the height of the GIB is also corrected to the appropriate height for expression of the particles. When the height of the GIB become taller than a border which is set based on the angle of repose, a part of the GIB spills from the container. To represent the spilling GIB, we use also same particles. The volume of the GIB on the container decreases according to spilling. These models are described in the references [5][6].

C. Toss of GIB

In addition to falling of a GIB, tossing of a GIB is also considered (Fig. 7). When a container with a GIB is shaken forcefully, the GIB is tossed upward. In the same way according to spilling, particles are used to represent the tossed GIB. And we use particles expressed based on a existence probability for interactive manipulation. The volume of the GIB on the container decreases by flying up, and increases by catching.

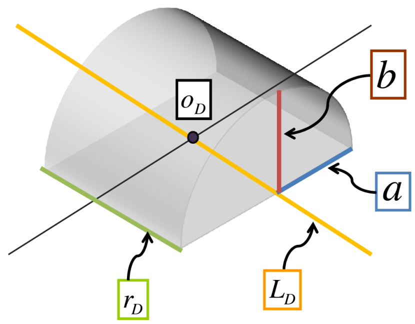

Fig. 4. Half of elliptic cylinder TS

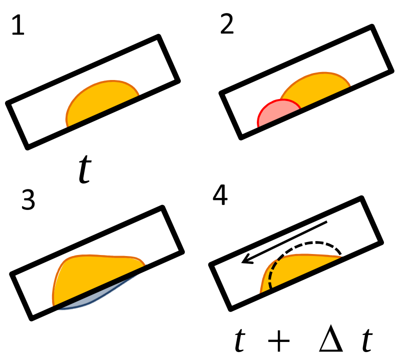

Fig. 5. Alternative process

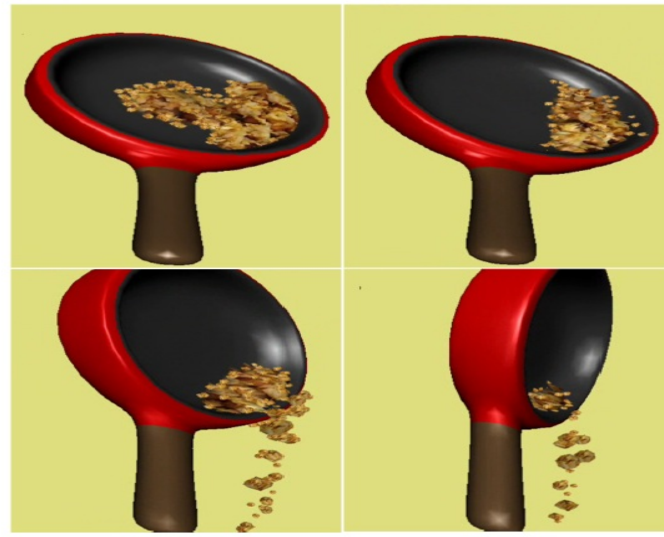

Fig. 6. Fall of GIB

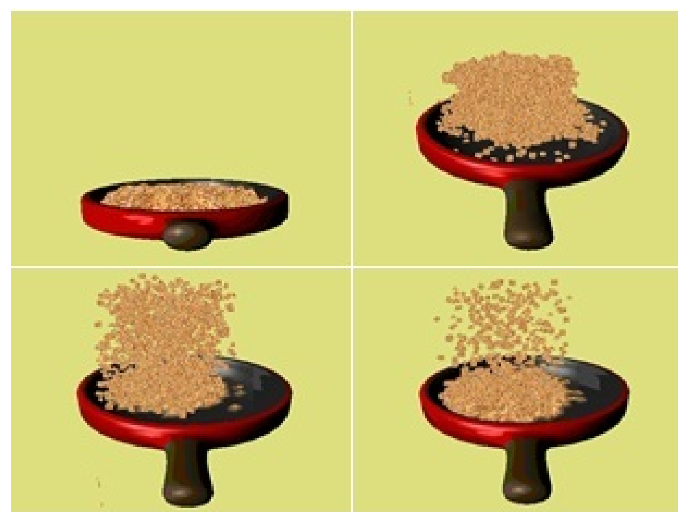

Fig. 7. Toss of GIB

D. Manipulation with Spatula

In II-A-2, a GIB is transformed with an indirect effect by tilting a container. We are also developing the mode to represent the GIB transformation with direct effect using cookware such as a spatula (Fig. 8). The GIB is pushed forward with a spatula and the volume of parts of the GIB change. To determine the behavior of the GIB, a TS which is a quarter of elliptic cylinder is applied.

III. GIB on Partial Sphere Container

A. Partial sphere container

In our previous model, we use a half elliptic cylinder TS because the container has a flat bottom. In other words, the model cannot be applied for the container with a convex bottom. Furthermore, it is difficult for the container to represent the correct shape. However, users do not require the representation of exact behavior of a GIB on such a container. The shapes of the containers often approximate a partial sphere. Thus, we enable to use a partial sphere container like a Chinese pan in our system (Fig. 9, 10). To determine the shape of the container, we define the depth of the container d_s and the width of the container opening r_s. The radius of the partial sphere R_s is calculated as below.

$$R_s = \frac{{d_s}^2 + {r_s}^2}{2d_s}. \tag{5}$$

In order to represent the shape of the partial sphere container, and since we would like to consider any shape container in the future, we define another height field for a container shape in our new model. We prepare a face on which the both of height fields of a GIB and a container is defined. We call the face the height field face (Fig. 11). The shape of container is represented as a partial sphere surface on it. The height of the container from the height field face h_s over the grid (x_i, y_j) is calculated as

$$h_s(x_i, y_j) = R_s - \sqrt{R_s^2 - (x_i^2 + y_j^2)}. \tag{6}$$

Fig. 8. GIB manipulation with spatula

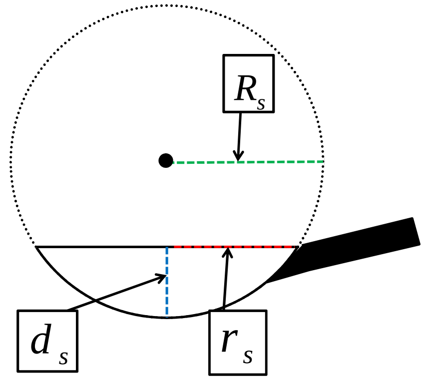

Fig. 10. Sphere containing container

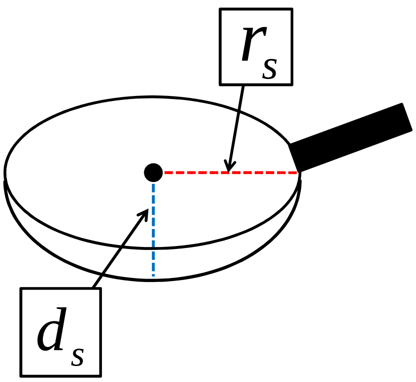

Fig. 9. Partial sphere container

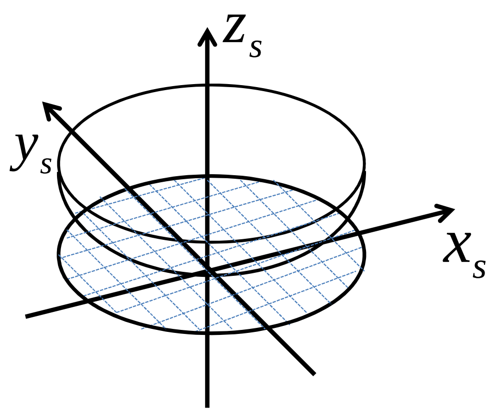

Fig. 11. Partial sphere on height field face

The top of the GIB on the container from the height field surface is determined with the height of the GIB and the container (Fig. 12). The height of the GIB top $h_{sum}(x_i, y_j)$ over the grid is calculated as

$$h_{sum}(x_i, y_j) = h(x_i, y_j) + h_s(x_i, y_j). \tag{7}$$

B. Transformation of GIB on partial sphere container

In the model using a partial sphere container, GIB transformation is affected by the convex bottom of the container. Thus, an applied TS is calculated with the angle and the direction of its inclination. When a GIB exists on a partial sphere container which is not tilted, it receives also the force toward the center of the container bottom. The shape of the TS on the cylinder container is defined as a half elliptic cylinder. However, the TS on the partial sphere container cannot be defined similarly. We think that a GIB on the partial sphere container would gather at a point, we apply a TS which is a half of spheroid (Fig. 13). The equatorial radius a' is and the polar radius b' of spheroid define the size of the TS. The core o'_D determines the place on which TS applied. The length a' is calculated from the volume of the GIB, and one of b' from the appropriate force the GIB received. The point of o'_D is determined from b' and the center of the GIB $\mathbf{G_c}$. These parameters are calculated in the same way as the previous model.

$$a' = T'_1\sqrt{V}. \tag{8}$$

$$b' = \left(\begin{array}{cc} (|\,\mathbf{F_b}\,| - \mu')T'_2\sqrt{V} & (|\,\mathbf{F_b}\,| \geq \mu) \\ 0 & (|\,\mathbf{F_b}\,| < \mu) \end{array} \right. . \tag{9}$$

$$\mathbf{o'_D} = \mathbf{G_c} + \frac{\mathbf{F_b}}{|\,\mathbf{F_b}\,|}a'. \tag{10}$$

The Constant T'_1 and T'_2 can be changed. We think a GIB on the partial sphere container receives reaction force by the angle of the bottom instead of the side. The TS is applied at the appropriate lower part of it to move the GIB (Fig. 14). Then in the same way as our previous model, the volume of the TS is added to one of the GIB. After that, the volume is corrected and the GIB finish moving.

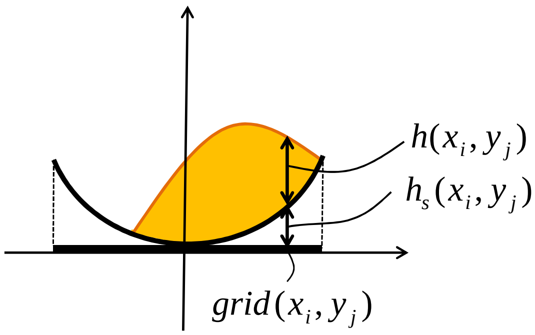

Fig. 12. Height of GIB on partial sphere container

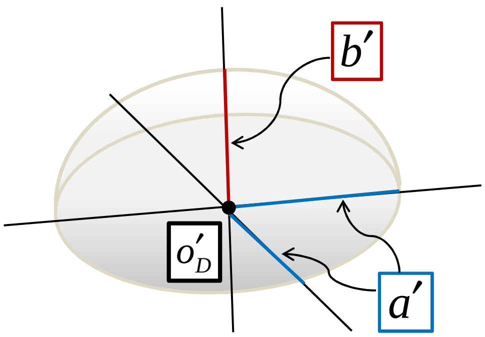

Fig. 13. Half of spheroid TS

IV. Experiment and Result

In this paper, we improved a GIB manipulation model for a partial sphere container. We constructed a experimental system with C++ language and DirectX. Users operate WiiRemote as a grip of a container to move a GIB (Fig. 15). The specification of PC is the following; CPU: Pentium(R) Dual-Core CPU E5200 2.50GHz, 1024MB RAM. In this system, the GIB is assumed as fried rice, and the container as a Chinese pan. Eight subjects evaluated the reality of a GIB movement by classifying the score into seven grades (Fig. 16). First grade is "This model does not feel real enough for a virtual cooking system." Seventh grade is "It is very similar to real one." According to the evaluation, we got a positive opinion. Moreover, we got some opinions that the difference of a GIB behavior on both of flat and convex containers is appreciable on the experiment system (Fig. 17). After that, we tested its performance (Tab. I). The left column shows the number the height field vertices, and the right is an average processing speed (FPS) rounded off. In advance, we have an opinion that

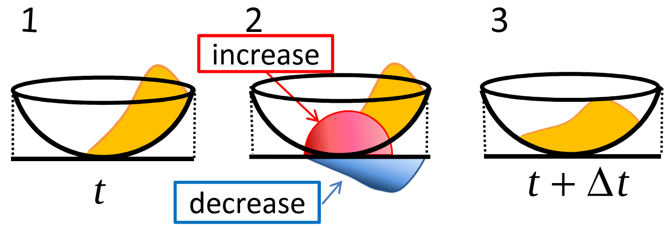

Fig. 14. Vertical section of GIB in partial sphere container

the GIB seems natural with 317 vertices. According to the result of the test, it seems too high speed, but the experimental system does not contain other models like the sections II-B, C, D.Moreover it is also necessary to compose models for other cooking process, such as washing, cutting and dishing to complete a virtual cooking system. Therefore, they are politic processing time.

TABLE I
Result of Performance Test

Vertices	Processing speed (FPS)
317	1563
529	1264
901	748
1373	620

Fig. 15. Appearance of experimental system

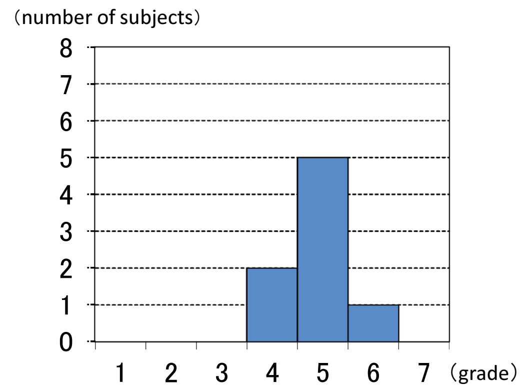

Fig. 16. Evaluation result of reality

V. Conclusion

In our manipulation model of a GIB, we use a height field and a TS to calculate the shape and transformation of a GIB quickly. However we had assumed to use only a cylinder container because of simplification. In this paper, we propose another new height field representing the shape of a container and the new TS for a partial sphere. By using them, we can represent movement of a GIB on a partial sphere container as naturally as a GIB on a cylinder container.

As a future work, we should improve our model to complicated form containers, which is composed with some different surfaces for example. We will consolidate different models we have proposed, such as falling, tossing, and moving with cookware. Moreover, we will also develop the models for other cooking processes such as cutting, washing and dishing. Finally, we will complete virtual cooking system.

Acknowledgment

We thank our colleagues in our laboratory for useful discussions. This work was supported in part by JSPS KAKENHI Grant Number 24501186.

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Fig. 17. GIB on each container (left: cylinder, right: partial sphere)

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