# The Collapse of Group of Indivisual Bodies Using Transformation Surface for Virtual Cooking System

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***Abstract*—We have researched an interactive manipulation model for a group of individual bodies (GIB) such as sand and lava. An exact calculation of a GIB behavior is quite complex, and the amount of calculation takes much time. Therefore we treat the GIB as one as one object. The GIB is represented as a height field, and variation of the height data represents a movement of the GIB. However a GIB collapse is calculated locally and sequentially. In this paper, we propose the new manipulation model which treats the whole of a GIB collapse as a kind of local GIB. In our model, the collapse is calculated with transformation surface same as the GIB manipulation model.**

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

## I. Introduction

In recent years, VR technology has been advanced remarkably and a lot of VR simulator has been developed in various fields, such as medical, industry, and education fields. As for the advantage of using VR system, reservation of safety and reduction of cost are mentioned. Users can receive a great benefit using these systems. However introduction of these systems to households is not progressing because the equipment used is huge or expensive. In contrast acquisition of the hardware which allows intuitive operation such as game controllers becomes possible at a low cost. Furthermore the spread of highly performance devices is also expected. Thus research on learning support system that targets to households has been carried out [1].

We focused on the cooking as a subject of VR content, and have been developing VR cooking learning system. This system is used for learning a procedure of cooking. The final purpose of this system is to learn a basic procedure of cooking (e.g. washing, cutting and dishing). Objects used in a cooking procedure are containers (e.g. skillet and pot), cookwares (e.g. knife and spatula), foods, and liquid material. In order to realize to manipulate these objects, it is required to represent behavior of solid (rigid and elastic) body and fluid. Behavior of objects represented in real time is also required to give a sense of realism to users.

By the way the representation of behavior of a gather of small bodies such as rice and a piece of foods is required to have experience of a cooking procedure. Research on lava flow [2], sand [3][4][5][6] and fluid [7] are mentioned as related ones. In the lava model [2] and sand model [3], the particle method is used and attempt to represent exact behavior. However an exact calculation of large number of bodies is quite complex and the amount of calculation takes much time, it requires to parallel calculation using GPU for real time simulation. The sand model [4] calculates its behavior sequentially based on the height field. Although behavior of sand is calculated with relatively high speed processing in this model, applying this model to application systems that require various processes is difficult.

On the other hand we define the object composed of plural bodies (such as ingredients) as a group of individual bodies (GIB), and propose interactive manipulation model of the GIB [8][9] which treats the whole of them as one object. In this model, behavior of each individual body composed of the GIB is not considered. Thus we enable both high speed calculation and representation of natural behavior that users manipulate without senses of discomfort. A GIB is affected the interference with cookwares and the gravity due to the changes of the pose of containers. These effect change the shape and the position of the GIB. In contrast collapse of the GIB is not treated in a lump. It is represented with simple, local and sequential calculation. Consequently collapse of the GIB processed in a single step is locally and sequentially calculation, and it spends considerable time to spread out.

In this paper, we propose a new GIB collapse model. First, we find the area where a part of GIB collapses. Next, we calculate collapse in that area as one object. In this model, we can maintain high speed processing and control the progress of collapse depending on the GIB property such as density and viscosity. We can also represent collapse of the GIB with versatility.

In section Ⅱ the GIB models is outlined, section Ⅲ describes the method for the proposed model, and the results of the proposed system is described in section Ⅳ.

## II. Manipulation model of GIB

### A. Container and GIB

In this model, a GIB is defined as a height field which is fixed on a container (Fig.1), and treated as one object. A container is constructed of a bottom composed of the convex polygon and the side perpendicular to the bottom. A two-dimensional grid is set to the container bottom. The shape

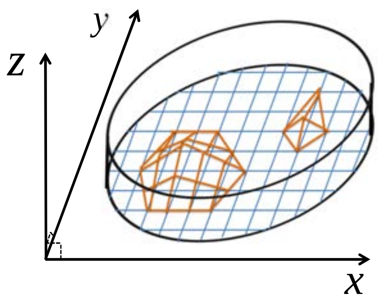


Fig. 1. GIB on a Container

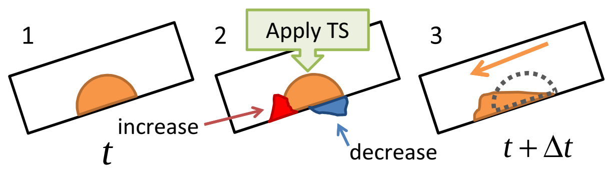


Fig. 2. Vertical Section of GIB and Container

of the GIB is represented as the set of the height of each grid. The GIB volume is represented as the sum of a part of GIB volume on each grid in a container. When the height of a grid coordinate $(x, y)$ is represented $h(x, y)$, a part of GIB volume $f(x, y)$ of grid$(x, y)$ is calculated with the height and a square measure. The GIB volume $V$ in a container $C$ is calculated as below.

$$V = \sum_{(x,y)\in C} f(x, y) \quad (1)$$

### B. Transform Surface

In this model, a GIB is manipulated as one object for decreasing the amount of calculation. Change of the height of each grid at short time interval represents behavior of a GIB, and the surface of the GIB is rendered using texture mapping. We represent a GIB behavior between short time interval in a curved surface which is defined as a variation of a GIB. We define that curved surface as a transform surface (TS). In fact, it is difficult to calculate the TS shape because a GIB behavior is complex. The TS is decided empirically in behavior of a GIB, it represents the plausible GIB transformation. When a container where the GIB exists in the center is inclined at time $t$, the GIB is expected to slide down to the lower part of the container (Fig.2-1). Then, the TS is applied around the GIB (Fig.2-2). As a result the GIB is moved (Fig.2-3). The TS is calculated from the physical effect such as the gravity and the reaction force.

### C. GIB Collapse without TS

There is the case that a part of a GIB collapses. In such a case is represented local and sequential calculation without the TS. Collapse of the GIB is calculated as follows.

1) Calculating differences of height $d$ between a observe grid $o(x, y)$ and two adjacent grids $s_1(x, y)$, $s_2(x, y)$ in direction of the center of a container.

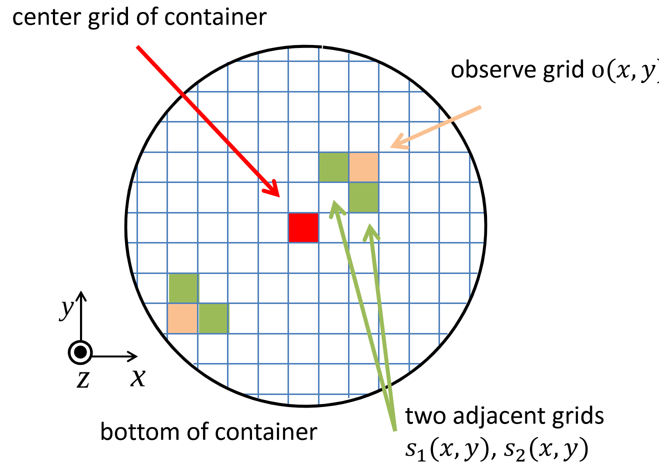


Fig. 3. Observe Grid and Two Adjacent Grids

2) If these differences are larger than the threshold value $t$, the height of those vertices are set the average value with the following condition.

   a) where $d_{s_1} > t \cap h_{s_2} > t$,
   $h(o(x, y)) = \frac{1}{3}(h(o(x, y)) + h(s_1(x, y)) + h(s_2(x, y)))$

   b) where $d_{s_1} > t \cap h_{s_2} \le t$,
   $h(o(x, y)) = \frac{1}{2}(h(o(x, y)) + h(s_1(x, y)))$

   c) where $d_{s_1} \le t \cap h_{s_2} > t$,
   $h(o(x, y)) = \frac{1}{2}(h(o(x, y)) + h(s_2(x, y)))$

   d) where $d_{s_1} \le t \cap h_{s_2} \le t$,
   $h(o(x, y)) = h(o(x, y))$

This process is carried out through finite times in one frame and the change of the height affects the whole of GIB gradually.

## III. GIB Collapse with TS

### A. Conventional Model and Proposed Model

In the conventional model, collapse of a part of a GIB is calculated locally. Progress of collapse is decided from the shape of the GIB. Consequently we can not control the progress of collapse depending on the GIB property such as

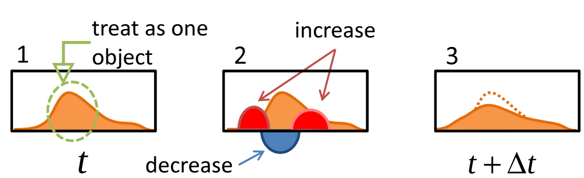


Fig. 4. Vertical section of GIB collapse

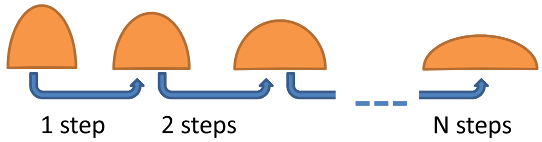


Fig. 5. Collapse of GIB in Conventional model

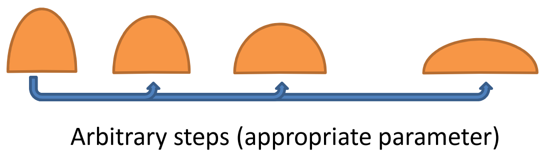


Fig. 6. Collapse of GIB in Proposed model

density and viscosity in the conventional model, because GIB collapse processed in a single step is locally and sequentially calculation, and it spends considerable time to spread out. Progress of collapse depending on the GIB property should be changed. The vertical section of the proposed model is shown in Fig.4. In proposed model, we consider collapse of a part of a GIB, and treat the collapse area as one object. The procedure of calculation of the collapse as follows.

1) Find candidates of vertices and areas where a GIB collapses
2) Reduce candidates
3) Decide whether the part of the GIB collapses in the area

In the conventional model, progress of collapse of a GIB certainly takes many steps (Fig.5). On the other hand the proposed model, we become possible to control progress of collapse at arbitrary steps applying an appropriate parameter (Fig.6).

### B. Shape of TS

We use the Gauss function to define a TS for collapse. Sectional views of a typical image of a GIB before and after collapse are shown in (Fig.7, 8). The difference between the two Gaussian surface is defined as the TS (Fig.9). A GIB which is piled up continues to collapse until it gets stable. Therefore we assume the change of the piled up GIB with shape during a certain time interval and use Gaussian surface as the piled up GIB with smooth slope.

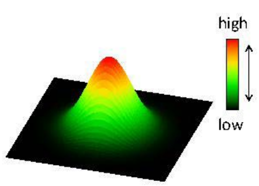


Fig. 7. Before Collapse

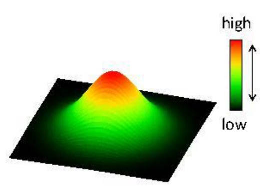


Fig. 8. After Collapse

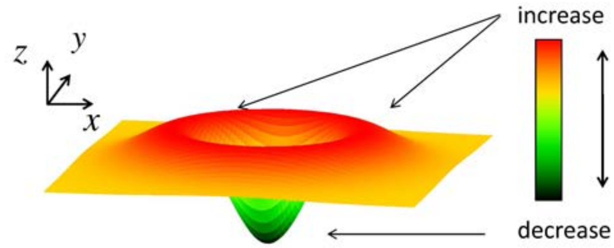


Fig. 9. TS of Collapse

### C. Find Candidates of Vertices where GIB collapse

First, we find the areas where a part of a GIB may collapse and the center point of that area. We compare the height of a observe grid and adjacent grids to check the state of the piled up GIB locally. When a observe grid is the grid $(x_i, y_j)$, we compare the height of the observe grid and four adjacent grids $h(x_{i-1}, y_j), h(x_{i+1}, y_j), h(x_i, y_{j-1}), h(x_i, y_{j+1})$ (Fig.10, 11, 12). If the height of the observe grid fulfills both following conditions,

$$h(x_i, y_j) > \frac{h(x_{i-1}, y_j) + h(x_{i+1}, y_j)}{2}, \tag{2}$$

$$h(x_i, y_j) > \frac{h(x_i, y_{j-1}) + h(x_i, y_{j+1})}{2}, \tag{3}$$

we treat the grid $(x_i, y_j)$ as a center point of the part of the GIB may collapse (Fig.12-4). We keep the top of the grid $(x_i, y_j)$ as a candidate of a vertex for collapse. It is represented as a three-dimensional coordinate $(x_i, y_j, h(x_i, y_j))$. Moreover we consider a candidate of an area. It is a cone which has the vertex candidate as its apex (Fig.13). We treat collapse in it as one object. An angle of the conic slope of the area is an angle of repose which represents the angle that the GIB piled up keeps stability.

### D. Reduce Candidates

In the above process, a lot of area candidates are detected. If we calculate collapse of a part of a GIB in each area, calculation time increases. Thus we reduce vertex candidates using area candidates. For example, an area with a vertex candidate $P$ includes other vertex candidate $Q$ (Fig.14). In

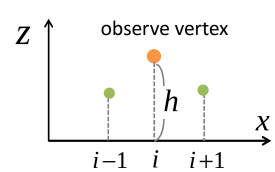


Fig. 10. Observe Vertex

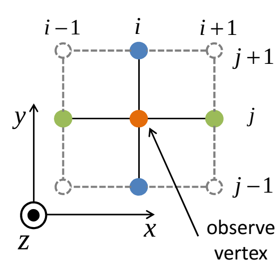


Fig. 11. Observe Vertex and Four Adjacent Grids Vertex

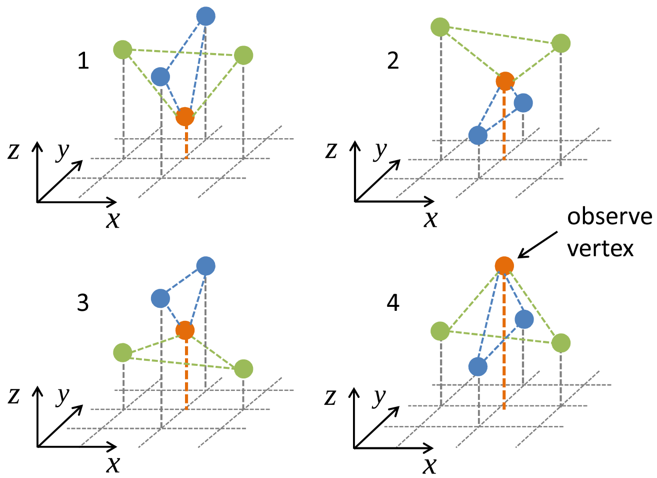


Fig. 12. Four Conditions with Observe Vertex and Adjacent Grids Vertex

Fig.14, we assume that $Q$ is included in the range of collapse centered at vertex $P$. We describe such collapse as collapse at $P$. Calculation of collapse at $Q$ is not considered and $Q$ is removed from the vertex candidate list. For example, the top of the area candidate $P$ and vertex candidates $Q_1, Q_2$ are shown in Fig.13. In Fig.13, $Q_1$ is removed from the vertex candidate list because it is inside the cone based on the area candidate. In contrast $Q_2$ is kept as the vertex candidate list because it is outside the cone. Vertex candidates are judged and reduced sequentially from the length vertex. After this process, we treat vertex candidates in the vertex candidate list as a final vertex candidates.

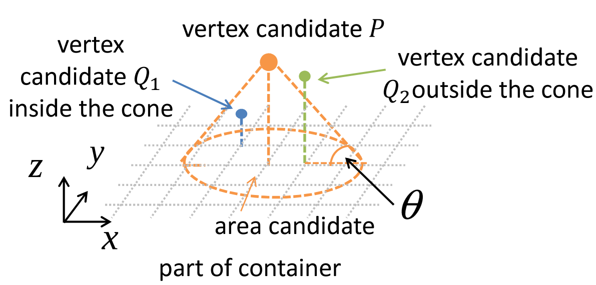


Fig. 13. Area Candidate and Vertex Candidates

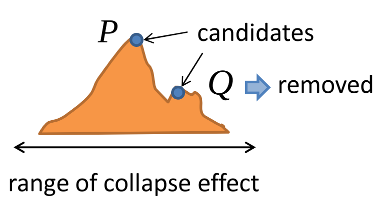


Fig. 14. Reduce Candidate

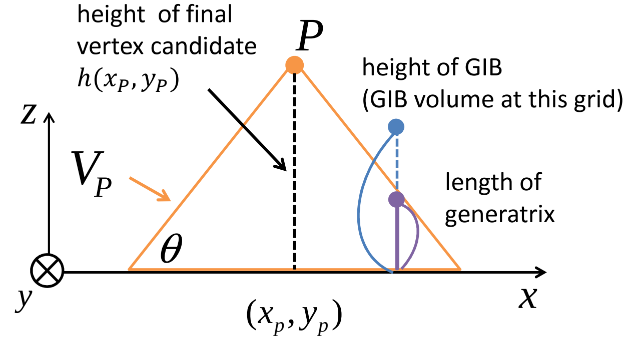


Fig. 15. Height of GIB, Generatrix and Final Vertex Candidate

### E. Decide whether GIB Collapses

We judge whether a part of a GIB collapses using area candidates based on the final vertex candidates. If a cone-shape GIB, for example, has the apex which is same height of $P$, and has smaller volume than the volume of the cone with the apex $P$ and the angle of repose $\theta$, the angle of the GIB slope is larger than the $\theta$. Although a shape of a GIB is of course different from a cone, we assume that the part of the GIB in the area collapses at $P$ when the GIB volume is smaller than the reposed volume (Fig.16). The volume of the cone based on the area candidate with the final vertex candidate $P$ is represented $V_p$, and the volume within the cone is represented $V_{GIB}$ (the volume inside the dashed line in Fig. 16). Both $V_p$ and $V_{GIB}$ are calculated as following equations (4),(5). Length of generatrix $gen(x_i, y_j)$ is the height of the perpendicular line from the generatrix to a bottom at the grid $(x_i, y_j)$.

$$V_p = \frac{(h(x_p, y_p))^3 tan^2\theta}{3}, \tag{4}$$

$$V_{GIB} = \sum_{(x,y)\in C} \begin{cases} f(x_i, y_j) : f(x_i, y_j) < gen(x_i, y_j) \\ gen(x_i, y_j) : f(x_i, y_j) \geq gen(x_i, y_j) \end{cases} \tag{5}$$

So $R = V_{GIB}/V_p < 1$, the part of the GIB should collapse. We apply a TS and the part of the GIB collapses. The central point $G$ of the TS is matched with the final vertex candidate $P$. We can represent difference types of collapse with appropriate

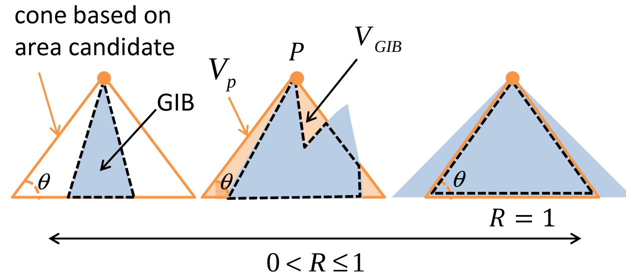


Fig. 16. Stability Judged with Angle of Repose and GIB Volume

TABLE I
PERFORMANCE RESULTS

| vertices | FPS |
|---|---|
| 317 | 1015 |
| 529 | 620 |
| 901 | 393 |
| 1343 | 203 |

steps using the scaled TS according to the size of the collapse area.

## IV. EXPERIMENT AND RESULT

We implemented the system based on the proposed model (Fig.17). The specification of PC is the following; CPU: InterCorei5-2400, 3.10GHz. In this experiment system, we used the Wii remote released from Nintendo Co., Ltd. A container is supposed as a skillet and a GIB as fried rice (not traditional Chinese fried rice but Japanese). Collapse of the GIB is represented in Fig.18. Moreover the difference of the progress of collapse is represented in Fig.19, 20.

We evaluated the proposed model (Table I). If the amount of a two-dimensional grid defined as a container bottom increases, the interval of the grid become narrow and a GIB is represented in more detail. We got an opinion that the GIB behavior is natural with 317 vertices in advance. According to the result, processing speed of the experiment is much faster than the speed that is required for interactive manipulation. However it is not excessive speed because we intend to add various procedure which includes manipulation model of a GIB using cookwares (such as a spatula), a vertical motion of GIB swinging containers (such as a skillet and a pot), dishing, and cutting to VR cooking learning system. Several subjects used and evaluated the system. We got some opinions that various types of the progress of collapse is represented. In the conventional model, we were able to make progress of collapse just slower. On the other hand we were not able to make it faster besides expanding the grid interval between each grid. Each parameter used in the experiment is determined empirically.

Fig. 17. Appearance of Experiment System

## V. CONCLUSION

In interactive manipulation model of a GIB we have been proposed, it is possible to calculate behavior of the GIB with high processing speed using a TS. However collapse of the GIB is calculated locally and sequentially. In this paper, we proposed the new GIB collapse model using transformation surface. First, we find candidates of vertices for collapse area locally. Next, we decide the collapse areas for collapse where a part of a GIB collapses. They are cone-shape and we treat the part of the GIB thereabouts. Finally, a TS which is made based on form of a GIB collapses is applied with appropriate parameter. Applying a TS to collapse, it is possible to control the progress of collapse depending on the GIB property such as density and viscosity. As the experimental result shows, the proposed model can operate with high processing speed. Therefore this model is useful for developed applications with interactive manipulation.

Future work may include the following. We should represent more detailed collapse behavior using various form TS. The purpose of our work is VR cooking learning system, it is necessary to develop other procedure models such as washing, cutting, and dishing.

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Fig. 19. Slow Collapse


Fig. 20. Fast Collapse

Fig. 18. Collapse of GIB