Representation of Wave Surface on Virtual Water Manipulation

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***Abstract*—In this paper, a model to realize an interactive manipulation of virtual water using a virtual container is described first. Then, this model is extended to represent the wave surface in the container. The mesh model are introduced for the wave representation so that the waves are propageted. Proposed system with this integrated model makes it possible to swing the water surface and to spill and/or stir the water.**

I. Introduction

Recent years, there are many studies of virtual reality that users can manipulate only the solid objects [1][2]. But, in the field of industry and the medical service, there are demands to make it possible to manipulate virtual fluid. So virtual fluid studies using the technique called SPH is performed [3][4]. In these studies, expression of correct fluid behavior is realized. However, there are some problems at a point of the drawing speed, and direct application to the interactive manipulation is still difficult.

On the other hand, the virtual water model named Particle and Volume Model is proposed [5], where a virtual container is introduced to detect the interference with water, and only the interaction between the virtual container and the water is treated. The main purpose of this model is the realization of the virtual water manipulation, while the generation of high quality computer graphics images nor simulating the exact behavior of the water are not the main. In addition, virtual water model to focus waves and splash of the water surface is proposed [6][7]. This model enables high speed processing without calculating the currrent water behavior.

The proposed method improves the Particle and Volume Model at the surface. The mesh model is used as the wave representation so that and the waves are propageted.

Our system with this proposed model makes it possible to catch the water using the virtual container, to spil the water by tilting the container, and to skim the water from another water container. Further, our system enables to wave the water surface with swinging the container.

II. Water Manipulation Using Container

In this section, a model to realize an interactive manipulation of virtual water using a virtual container is discribed [5]. Our system is based on this virtual water model.

A. Virtual Water in Virtual Space

In this study, the water is concidered under the following conditions.

(1) free fall condition (such as flowing water from a faucet)
(2) stay condition (such as holding water in a cup)

The proposed model represents the water in the condition (1) as particles. Each particle moves according to the gravity and the inertia. It is assumed that the size of the particle is ignored and each particle does not interfere with other particles.

While, the water in the condition (2) is represented as volume. The exchange rate between each condition is taken to be N [number of particles / volume]. When user falls all water by tilting the container of the volume V, the volume of water in the container becomes 0 and the number of particles of water in free fall condition increases by NV.

B. Virtual Container in Virtual Space

A container with the convex shape is used and a sphere including the container (Fig. 1) is introduced for detecting the interference. The center of the sphere is designated as C and its radius is designated as r. Then, the position of the container is represented by C. The direction of the container is represented by θ, ϕ and ψ (Fig. 2), while the tilt parameters are represented by θ and ϕ. First, a container is rotated by ϕ on axis x_c, and rotated by θ on axis z_c. Then it is rotated by ψ on axis y_c. When θ and ϕ of a container are set to be 0 respectively, the status means that it is not tilted.

Fig. 3 shows a virtual container with the water. Functions of the container with the water are defined in the following. The over flow point F is represented by the relative vector from the point C.

$$F = f(\theta, \phi, \psi). \quad (1)$$

When the volume of the water in a container is V $(V \geq 0)$, the height level of the water surface H is represented by the relative distance from the point C.

$$H = h(\theta, \phi, V). \quad (2)$$

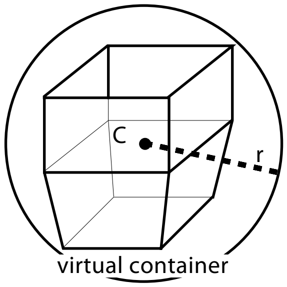

Fig. 1. Virtual container and a sphere including it

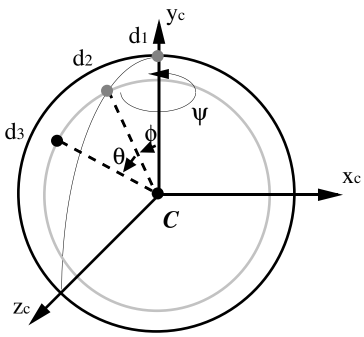

Fig. 2. Representation of tilting of virtual container

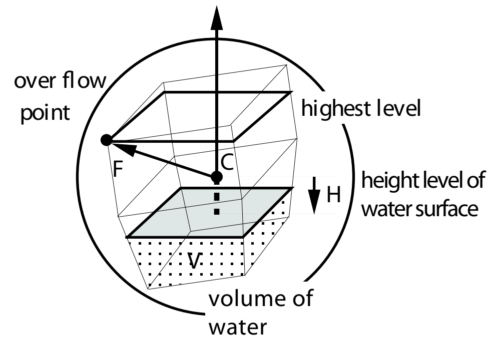

Fig. 3. Each parameter of virtual container

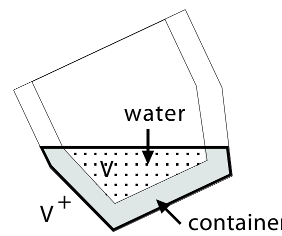

Fig. 4. Volume considering thickness of virtual container

When the parameter V of the function h is over the maximum volume Vm, H becomes F_y (F_y is defined as the vertical coordinate of F). The above equation is translated to

$$V = v(\theta, \phi, H). \tag{3}$$

When the parameter H of the function v is under the container, V becomes 0. When H is above the point F, V is taken as $v(\theta, \phi, F_y) = Vm(\theta, \phi)$ (F_y is independent of ψ).

When the height level is H, define the volume under H considering the thickness of container (Fig. 4) as

$$V^+ = v^+(\theta, \phi, H). \tag{4}$$

When the volume of water is Vm, V^+ becomes Vm^+. When the thickness of container is not considered, V^+ is regarded as V.

C. Interaction Model of Water and Container

First, this system gets $C(t), \theta(t), \phi(t)$ and $\psi(t)$; the position and the direction of the container moved by the user in the virtual space. (This can be done using the 3-D position sensor.) In the following discussions, the value at time t is assumed when the description of the parameter t is omitted. Each particle is moved according to the gravity and the inertia. The particles moved under the predefined threshold plane will be deleted for the drawing.

1) Water in Free Fall Condition and Container: When the falling water (each particle) moves through the mouth of a container, the status of the water changes from the condition (1) to the condition (2), and the volume of the water in it will be increased according to the exchange rate N (Fig. 5).

$$V(t) = V(t - \Delta t) + n/N, \tag{5}$$

where n ($n \geq 0$) means the number of particles which move through the mouth. When the water in the container is not interfered with another container, the height level is updated simply according to the equation (2).

2) Water in Stay Condition and Container: In this section, it describes the interaction model between a container and the water in another container. In the following, let each container be designated as *container 1* and *container 2* respectively, also let the symbol of each container be designated as subscript 1 and 2 for the distinction. When the equation (6) holds, container 1 and the water in container 2 are interfered each other (Fig. 6).

$$C_{1y} - r_1 < C_{2y} + h_2(\theta_2, \phi_2, V_2), \tag{6}$$

$$C_{2y} + h_2(\theta_2, \phi_2, V_2 + Vm_1^+) < C_{1y} + F_{1y}, \tag{7}$$

where C_{jy} is the vertical coordinate of the position C_j.

When the equation (7) also holds, the situation is that the part of container 1 under the over flow point interferes with the water surface of container 2. Then, let the volume that container 1 upholds the height level of container 2 be U. When it does not hold, the situation is that the water in container 2 flows into container 1, the volume of the water in each container is changed with the appropriate rate [5].

3) Spilling water from Container: When next equation holds at time t by the above interference and tilting of a container, the water spills from the container (Fig. 7).

$$V + U > Vm. \tag{8}$$

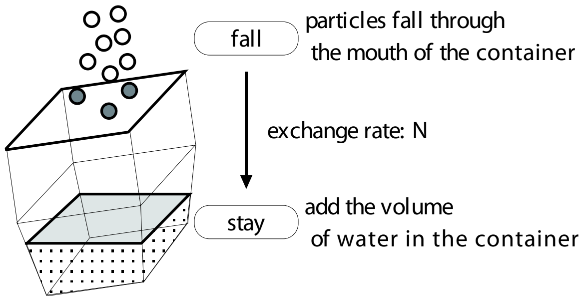

Fig. 5. Relation between two conditions of water (1)

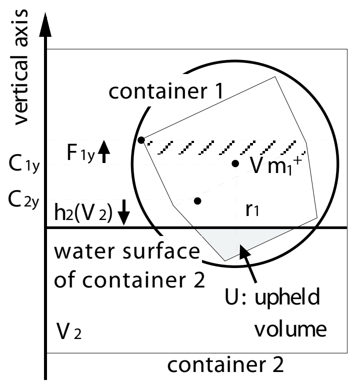

Fig. 6. Interference between virtual container and water of another container

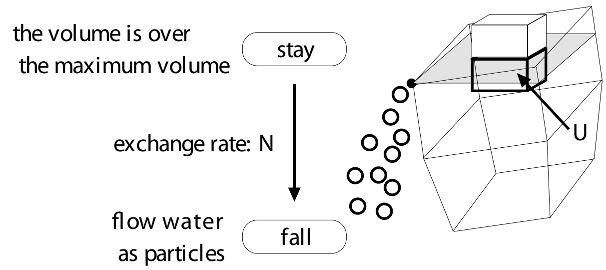

Fig. 7. Relation between two conditions of water (2)

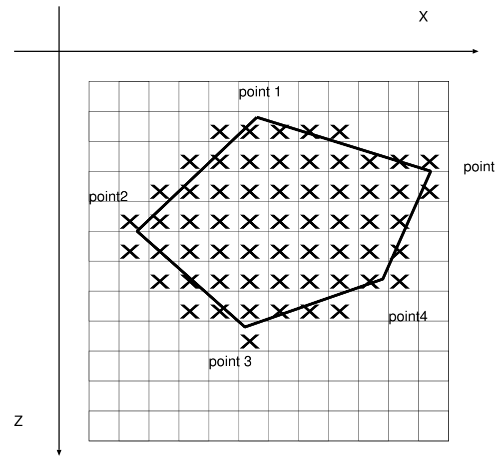

Fig. 8. A meshed surface and grid points in a polygon

The part of the water in the container, which is expressed using the volume, spills at the over flow point F as $N(V + U - Vm)$ particles according to the gravity. The volume in the container at time t is determined as

$$V(t) = Vm - U. \tag{9}$$

While if the equation (8) does not hold, the water dose not spill.

III. Model of Wave

As another virtual water study that we refer, there is a method to express water wave and splash for virtual swimming as artwork; Swimming Across the Pacific [6][7].

A. Representation of Wave

This water simulation is based on the method in which the water surface is modeled as a thin film. For the sea surface plane waves, the systems use recurrence relations to solve the partial differential equation for the 2D wave. The sea surface is modeled as a mesh in this method. The height of the grid at point $[i][j]$ at time $t+\Delta t$ on the sea surface is $h[i][j][t+\Delta t]$. And the height $h[i][j][t+\Delta t]$ is determined as

$$\begin{aligned} h[i][j][t+\Delta t] = \quad & (h[i-1][j][t] + h[i+1][j][t] \\ & + h[i][j-1][t] + h[i][j+1][t]) \\ & / \left(2 - h[i][j][t-\Delta t]\right). \end{aligned} \tag{10}$$

B. Interaction between surface and objects

In this system, the vitual object consists of some bounding boxes. When they move and intersect with any of the water grids, the height of the gird is reset as follows:

- When the bounding box goes into a water grid, the height of the grid increases with a predefined value.
- When the bounding box goes out from the water surface, the height of the grid decreases with a predefined value.

When these two conditions occur, the system makes waves and propagates them.

IV. Representation of Waving Water

A. Formation of Water Surface

In our system, a part of waving water is based on the model of a wave mentioned above. The model of the wave, the surface is limited to only rectangle, while, the surface of virtual water in a container is represented by any polygon. The water surface is modeled as a mesh, so we note grid points to display the multilaternal surface (Fig. 8).

Then, the grid points shown as X in the Fig. 8 are simply calculated, and they form the water surface in the container. In this way, any multilaternal surface can be displayed in a short time.

B. Wave with Shaking Container

For the water in the glass in reality, a wave occurs according to the movement of the glass. This paper realizes the behavior

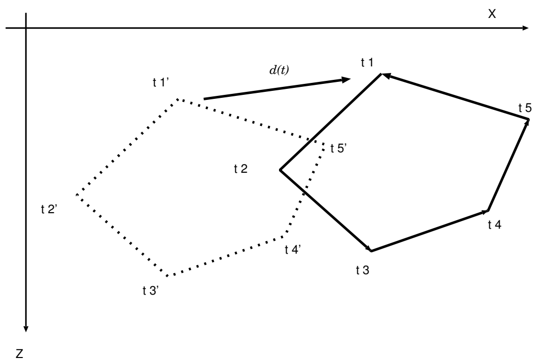

Fig. 9. Movement of the water surface and moving vector

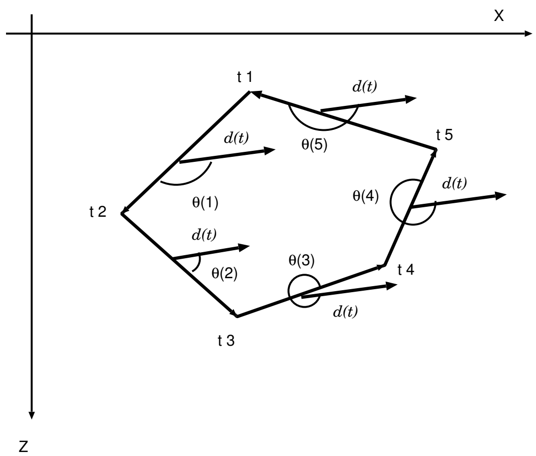

Fig. 10. Included angles

of the surface by performing a simple vector calculation when a container is moved. The moving vector of its poisition is defined as d(t). The container moves three-dimensional virtual space in general, but we treat 2 dimensions of d(t) to pay attention to the movement of the surface (Fig. 9,10).

When the container moves, the system judges the included angles $\theta(n)$. When $\theta(n)$ are less than 180 degree, waves are generated at the face of wall.

C. Virtual Water

1) Interaction between the Container and the Surface: When a countainer includes water of other containers, a hole is opened in the surface according to shapes of the container. In addition, the behavior is realized that when the water of container reachs the surface or moves in water according to the above-mentioned model of the wave.

2) Interaction between the Falling Water and the Surface: When the water (particles) in free fall condition reaches the surface, waves are generated at the surface. We convert the position $P_i(t - \Delta t)$ of particles reaching the surface just before that into a container coordinate system from a three-dimensional image coordinate system. And according to the position, it decreases the height of the grid point.

TABLE I
COMPARISON OF DRAWING UPDATE SPEED

		Conventional model	Proposed model
Mouse	Only drawing	250fps	120fps
	Operating	230fps	80fps
Motion senser	Only drawing	65fps	60fps
	Operating	65fps	60fps

V. EXPERIENTAL RESULTS

The virtual water system using the model mentioned above was implemented with C language. The specification of PC used is the following; CPU: AMD Athlon(tm) MP Processor 1.2GHz × 2. The exchange rate N is taken to be 10 [number of particle / cc]. In the experiment, 1 cc of the failling water is generated per 1 CG frame.

An example operation is shown in Fig. 11. Our system has two containers. One is a movable container and it can be controlled by the user. Another is a fixed large container. We gets the position and the direction of the movable container from a real cup with the motion sensor using a low-frequentry magnetic field. The device we used is 3SPASE ISOTRAK2 of Polhemus company.

As shown in the Fig. 12, the user can spill the water and the surface waves when the falling water reaches another water surface. Fig. 13 shows that containers interact with virtual water. The surface of virtual water waves according to moving the container in the water. If we replace the container to a spoon, we can experience the virtual water manipulation using a virtual spoon, as shown in Fig. 14.

We compare our system with Particle and Volume model (conventional approach) from the aspect of the drawing update speed [fps].

The results are shown in TABLE1, and it is suggested that our system has enough processing speed for an interactive manipulation of virtual water. Through the experiments of this virtual water manipulation system in our laboratory, we got some positive evaluation like;

- It looks like a real water considerably.
- It feels that the virtual container and virtual water are operated by myself.

These results lead to the conclusion that an interactive manipulation of virtual water was achieved.

VI. CONCLUSIONS

In this paper, we proposed a model for water manipulaion using virtual containers and realized the implementation of an experimental system as a virtual reality system. Using the virtual container, the system can swing the water, and wave the water surface at an interactive refresh rate. Also the system can catch the falling water, skim the water from another container. The representation of splash in the Virtual Swimming System has been extended to achieve our system. The following subjects are remained as the future subjects.

- Representation of the virtual current.

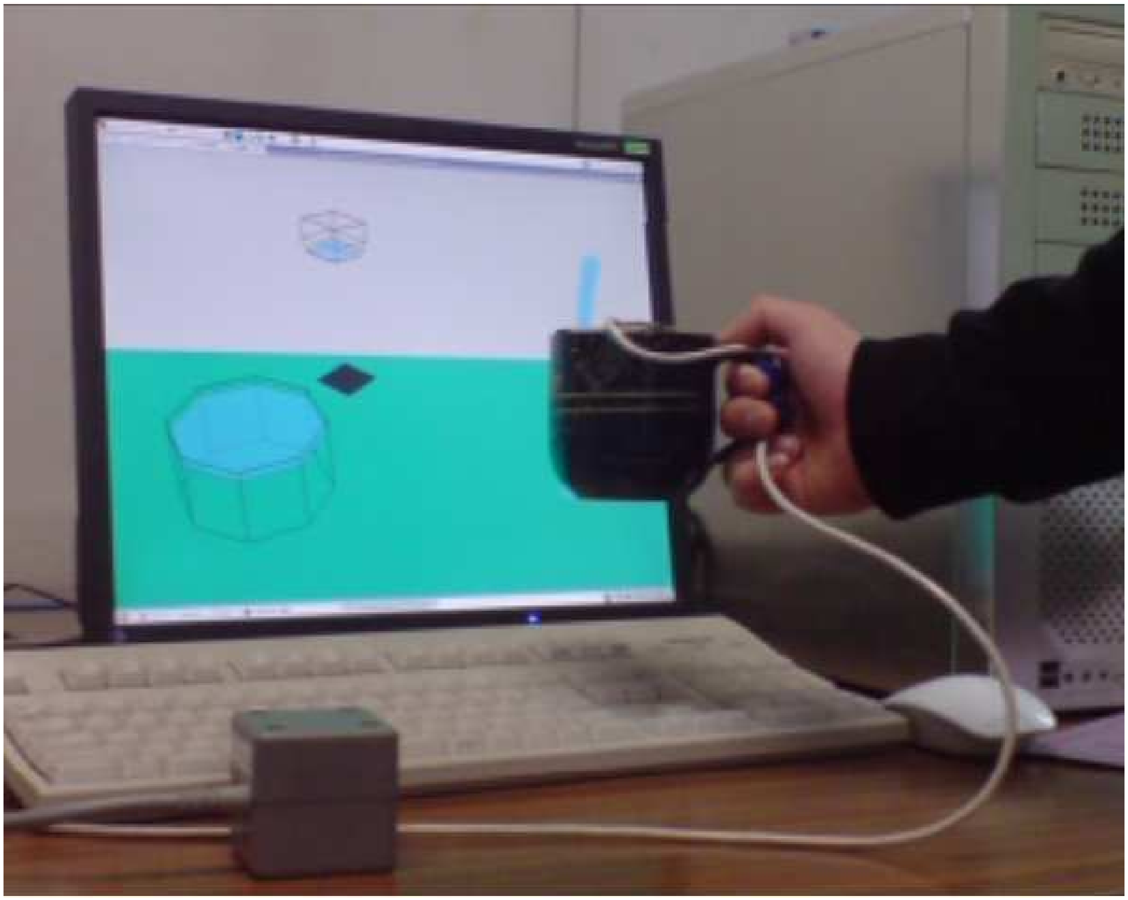

Fig. 11. Environment of experiment

- Interaction with the water which has information of colors.
- Interaction between the virtual water and the virtual object which has information of weight.

As an application of this approach, there is a work to apply our system with VR contents. The ideas are now under consideration but "Virtual Cooking System" is developped in our laboratory as an example [8].

REFERENCES

[1] S.Suzuki, M.Yamada, S.Miyazaki, J.Hasegawa, T.Yasuda, S.Yokoi. Real-time Elastic Object Interaction Constructed by Computation Accelerated Elastic Models, *The Jornal of the Society for Art and Science*, Vol.2, No.1, pp.8-14, 2003.

[2] X.Guo, J.Hua, H.Qin. Touch-Based Haptics for Interactive Editing on Point Set Surfaces, *IEEE CG& A*, pp.31-39, 2004.

[3] M.Muller, S.Schirm, M.Teschner. Interactive Blood Simulation for Virtual Surgery Based on Smoothed Particle Hydrodynamics, *ACM Technology and Health Care*, Vol.12, No.1, pp.25-31, 2004.

[4] M.Imura, T.Amada, Y.Yasumuro, Y.Manabe, K.Chihara. Interaction with Virtual Fluid in Mixed Reality Environment, *Transactions of the Virtual Reality Society of Japan*, pp.549-552, 2005.

[5] K.Funahashi, Y.Iwahori. Representation of Swinging Liquid on Virtual Liquid Manipulation, *Proc. ICAT2001*, vol.11, pp.179-184, 2001.

[6] K.Funahashi, Y.Iwahori. Expression of Water Wave and Splash for Interactive Virtual Swimming, *Transactions of the Virtual Reality Society of Japan*, Vol.10, No.3, pp.421-428, 2005.

[7] S.Fels, Y.Kinoshita, T.G.Chen, Y,Takama, S.Yohanan, S.Takahashi, A.Gadd, K.Funahashi. Swimming Across the Pacific: A VR Swimming Interface, *IEEE CG& A*, Vol.25, No.1, pp.24-31, 2005.

[8] S.Oguri, K.Funahashi. A Study of a Group of Individual Bodies Model for VR Cooking System, *The Graduation Thesis of Nagoya Institute of Technology*, 2008.

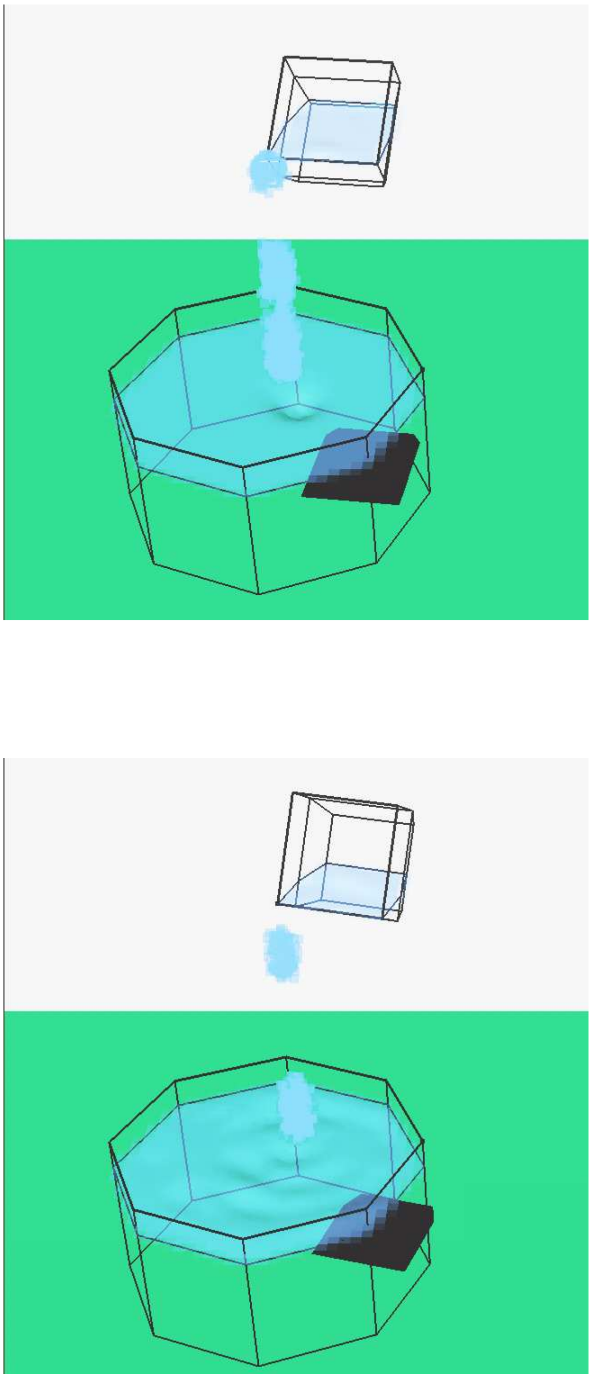

Fig. 12. Falling water

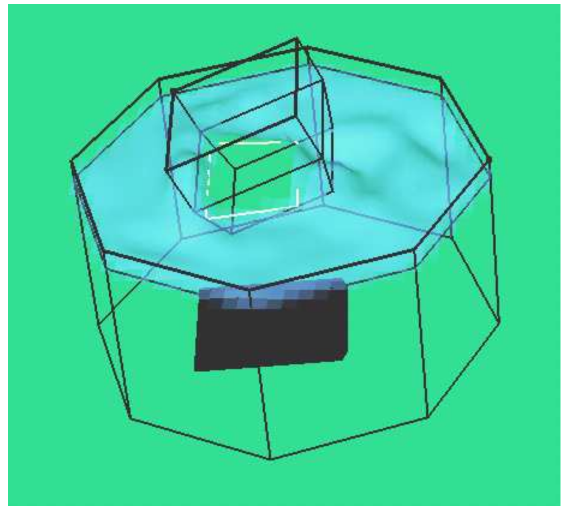

Fig. 13. Interaction between container and surface

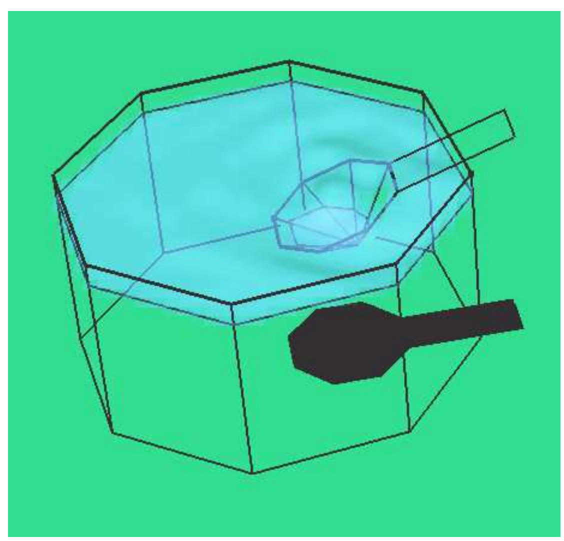

Fig. 14. Interaction between container and surface