A Model for Liquid Manipulation Using Vessel in Virtual Space

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ABSTRACT

This paper describes a method to realize an interactive manipulation of virtual liquid using virtual vessels which are expressed by the general convex shape polyhedron. We have proposed the liquid manipulation model which has some functions to treat the relation between the volume of liquid in a vessel and the height level of liquid surface in it while it is tilted. For a general shape vessel, the look up table to calculate the above functions is implemented. Our system with this proposed model makes it possible to catch the liquid using the virtual vessel, to hold the liquid in it, then to spill the liquid by tilting it. Also the system realizes the manipulation to skim the liquid from another liquid vessel.

Keywords: Virtual Reality, Virtual Liquid, Interactive Manipulation, Liquid Model, Particle and Volume Model

1. INRTODUCTION

In the field of virtual reality for the recent years, many researches such as [1], [2], [3] have been performed for the interactive manipulation in virtual space. In the conventional researches, the limitation is that users can manipulate only the solid objects under these systems. However, there are many situations that manipulate liquid or gas object, as in the cooking or in the amusement.

In the field of the hydrodynamics, research on the analysis of behavior of the liquid has been performed, while in the computer graphics technology, the scene image of water current have been represented by real-time simulation [4], [5], [6]. However, an interactive manipulation of the virtual liquid is not considered in that and other studies.

In this paper, an interactive model to manipulate virtual liquid using a virtual vessel [7] is described first. A virtual vessel is introduced to detect the interference with liquid. We consider only the interaction between the virtual vessel and the liquid not that between the general object and the liquid. Then, a method is extended to realize an interactive manipulation of virtual liquid using a virtual vessel which is expressed by the general convex shape polyhedron. The model represents the liquid in the free fall condition as particles, while it does that in the stay condition as volume. It has some functions to treat the relation between the volume of liquid in a vessel and the height level of liquid surface in it while it is tilted. For a general shape vessel, the look up table to calculate the above functions is implemented. The main purpose of this model is the realization of the virtual liquid manipulation, while the generation of high quality computer graphics images or simulating the exact behavior of the liquid, are not the main.

Our system with this proposed model makes it possible to catch the liquid using the virtual vessel, to hold the liquid in it, then to spill the liquid by tilting it. Also the system realizes the manipulation to skim the liquid from another liquid vessel.

2. MODEL FOR VIRTUAL LIQUID AND VESSEL

Virtual Liquid in Virtual Space

In this paper, we consider the liquid 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 liquid 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 liquid in the condition (2) is represented as volume. The exchange rate between each condition is assumed to be N [particles / volume]. When user falls all liquid by tilting the vessel of the volume V, the volume of liquid in it becomes 0 and the number of particles of liquid in free fall condition increases by NV.

Model of Virtual Vessel

We consider a vessel with the convex shape and a sphere including the vessel (Fig. 1). The center of the sphere is designated as C and its radius is designated as r. Then, the position of the vessel is represented by C. The direction of the vessel is represented by θ,ϕ and ψ (Fig. 2), while the tilt is represented by θ and ϕ. First, a vessel 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 vessel are set to be 0 respectively, the status means that it is not tilted.

Fig. 3 shows a virtual vessel with the liquid. First, functions of the vessel with the liquid are defined in the following. The over flow point F is represented by the relative vector from the point C.

$$F = f(\theta,\phi,\psi). \tag{1}$$

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

$$H = h(\theta,\phi,V). \tag{2}$$

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

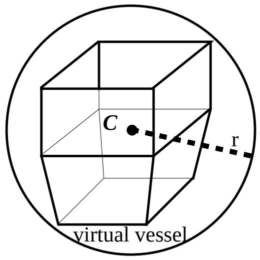

Figure 1: Virtual vessel and a sphere including it

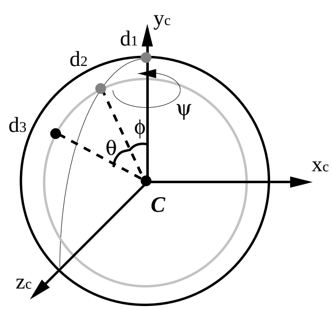

Figure 2: Representation of tilting of virtual vessel

of F). The above Eq. is translated to

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

When the parameter H of the function v is under the vessel, 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 vessel (Fig. 4) as

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

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

3. INTERACTION OF LIQUID AND VESSEL

First, the system gets the position and the direction $(C(t), \theta(t), \phi(t), \psi(t))$ of the vessel 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.

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

$$V(t)^{(0)} = V(t - \Delta t) + n/N, \tag{5}$$

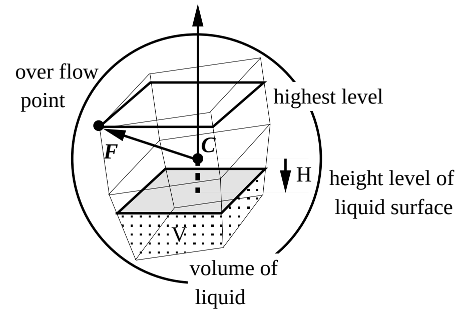

Figure 3: Each parameter of virtual vessel

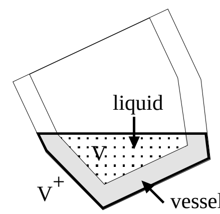

Figure 4: Volume considering thickness of virtual vessel

where n ($n \geq 0$) means the number of particles which move through the mouth and $V(t)^{(0)}$ means the assumed volume. When the vessel dose not interfere with the liquid in another vessel, let the assumed volume of the liquid in the vessel at time t be $V(t)^{(1)}$ $=V(t)^{(0)}$. Then the height level is updated according to

$$H(t) = h(\theta, \phi, V(t)^{(1)}). \tag{6}$$

Liquid in Stay Condition and Vessel
In this section, we describe the interaction model between a vessel and the liquid in another vessel (Fig. 6). In the following, let each vessel be designated as *vessel 1* and *vessel 2* respectively, also let the symbol of each vessel be designated as subscript 1 and 2 for the distinction. When next Eq. holds at time t, vessel 1 and the liquid in vessel 2 are interfered each other.

$$C_{1y} - r_1 < C_{2y} + h_2(\theta_2, \phi_2, V_2^{(0)}), \tag{7}$$

where C_{jy} is the vertical coordinate of the position C_j of vessel j. When the interference is detected, let the volume that vessel 1

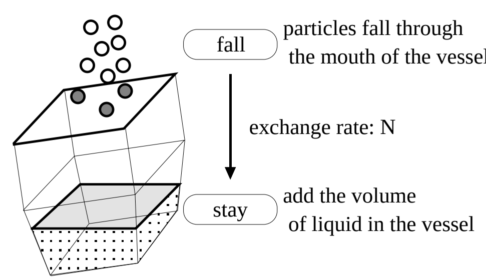

Figure 5: Relation between two conditions of liquid (1)

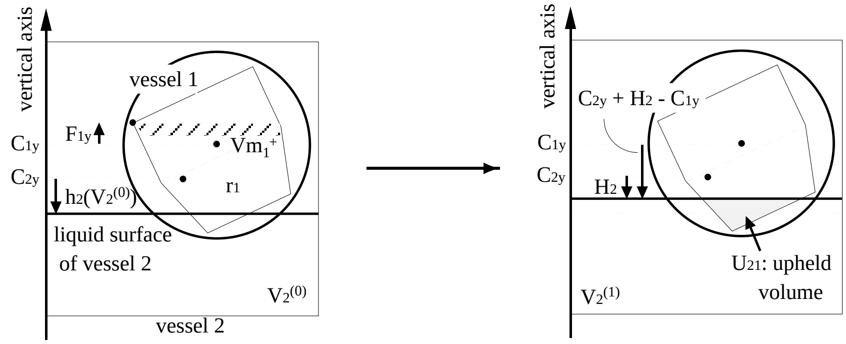

Figure 6: Interference between virtual vessel and liquid of another vessel

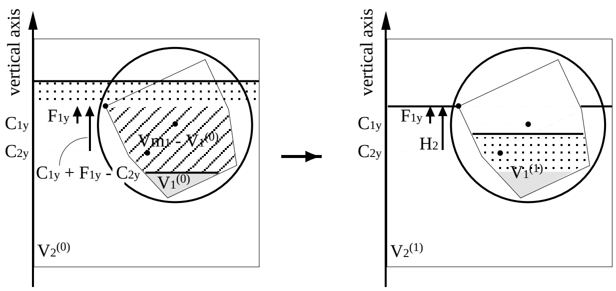

Figure 7: Flowing liquid into virtual vessel (1)

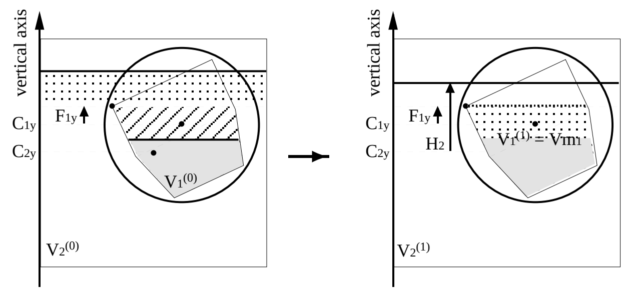

Figure 8: Flowing liquid into virtual vessel (2)

upholds the height level of vessel 2 be $U_{21} \geq 0$. Let the volume that other vessels uphold the height level of vessel 2 be

$$U_2 = \sum_j U_{2j}. \tag{8}$$

When vessel 1 and the liquid in vessel 2 are interfered each other and next Eq. holds, the situation is that the part of vessel 1 under the over flow point interferes with the liquid surface of vessel 2.

$$C_{2y} + h_2(\theta_2, \phi_2, V_2^{(0)} + Vm_1^+) < C_{1y} + F_{1y}. \tag{9}$$

When the above Eq. does not hold, the situation is that the liquid in vessel 2 flows into vessel 1.

Upholding of Liquid Surface: When a vessel and the liquid surface are interfered each other, vessel 1 upholds the liquid surface of vessel 2. The height level H_2 of vessel 2 should satisfy next Eq.

$$\begin{aligned} H_2 &= h_2(\theta_2, \phi_2, V_2^{(0)} + U_{21}), \\ U_{21} &= v_1^+(\theta_1, \phi_1, C_{2y} + H_2 - C_{1y}). \end{aligned} \tag{10}$$

Let the volume in each vessel $V_j^{(0)}$ be updated as $V_j^{(1)}$. Then the height level of vessel 1 is determined from the Eq. (6).

Flowing of Liquid into Vessel: When the liquid in vessel 2 flows into vessel 1 and the next Eq. holds, the height level of liquid in vessel 2 should be the height of the over flow point of vessel 1 (Fig. 7).

$$\begin{aligned} V_2^{(0)} + U_{21} - v_2(\theta_2, \phi_2, C_{1y} + F_{1y} - C_{2y}) \\ < Vm_1 - V_1^{(0)}. \end{aligned} \tag{11}$$

When the liquid flows into a vessel, vessel 1 upholds the height level of vessel 2 with the volume $U_{21} = Vm_1^+$. The height level of vessel 2 should be the height of the over flow point of vessel 1 (Eq. (12)). The volume of each vessel is determined from the Eq. (13) and (14). Then, the height level of vessel 1 is determined from the Eq. (6).

$$H_2 = (C_{1y} + F_{1y}) - C_{2y}. \tag{12}$$

$$V_2^{(1)} = v_2(\theta_2, \phi_2, H_2) - U_{21}. \tag{13}$$

$$V_1^{(1)} + V_2^{(1)} = V_1^{(0)} + V_2^{(0)}. \tag{14}$$

When Eq. (11) does not hold, the liquid surface of vessel 2 should be higher than the height of the over flow point of vessel 1 (Fig. 8). Then, the volume $V_1^{(1)}$ and the height level H_1 of vessel 1 are set as the maximum volume Vm_1 and the radius r_1, respectively, where the liquid surface of vessel 1 is not considered (not drawn). The volume and the height level of vessel 2 are determined from the Eq. (14) and next Eq.

$$H_2 = h_2(\theta_2, \phi_2, V_2^{(1)} + U_{21}). \tag{15}$$

When the liquid does not flow into another vessel, user can skim

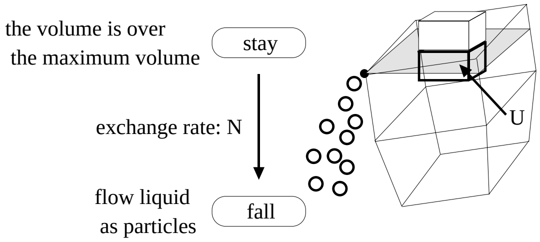

Figure 9: Relation between two conditions of liquid (2)

the liquid with the vessel by the above process.

Spilling Liquid from Vessel
When next Eq. holds at time t by the above interference and tilting of a vessel, the liquid spills from the vessel (Fig. 9).

$$V^{(1)} + U > Vm. \tag{16}$$

The part of the liquid in the vessel, which is expressed using the volume, spills at the over flow point F as $N(V^{(1)} + U - Vm)$ particles. The volume in the vessel at time t is determined as

$$V(t) = Vm - U. \tag{17}$$

While if the Eq. (16) does not hold, the liquid dose not spill and the volume $V(t)$ becomes $V(t)^{(1)}$.

Drawing and Other Processes
The virtual faucet which flows the infinite liquid is defined for the experiment of the interaction between a virtual vessel and the liquid in the free fall condition. After the above processes, liquid particles are generated from the faucet.

Actual shape of the liquid surface of each vessel is generated for the drawing of the CG image based on the shape of the vessel and the height level. When vessel 1 interferes with the liquid in vessel 2 and the height level of vessel 2 is not higher than the over flow point of vessel 1, it is necessary that the part of the liquid surface of vessel 2 should be removed for vessel 1.

Then, each particle, each vessel, its liquid surface and its shadow are drawn.

4. IMPLEMENTATION GENERAL SHAPE VESSEL

For the implementation of a system, each function of each vessel expressed by Eq. (1) - (4) should be made based on the shape of each vessel respectively. In this system, virtual vessels are expressed by convex shape polyhedron. At loading up the shape of vessels, the LUTs (look up table) for each vessel are made to calculate the Eq. (3). This LUT gives V from the parameter θ, ϕ and $H \cdot 100/r$, where $-90 \leq \theta \leq 90$ $(degree)$, $-180 \leq \phi \leq 180$ $(degree)$ and $-100 \leq H \cdot 100/r \leq 100$ $(-r \leq H \leq r)$, with step $\Delta\theta, \Delta\phi$ and ΔH, respectively (Fig. 10). In this LUT, if the height level is under the vessel, the volume is set to 0. If it is above the over flow point, the volume is set to the maximum volume $Vm(\theta, \phi)$. This system has only cubic area shown with thick lines in Fig. 11 on a memory.

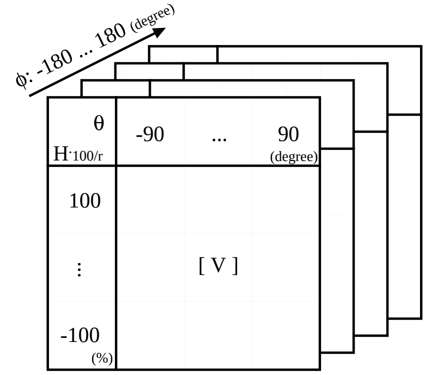

Figure 10: Look up table for calculation volume

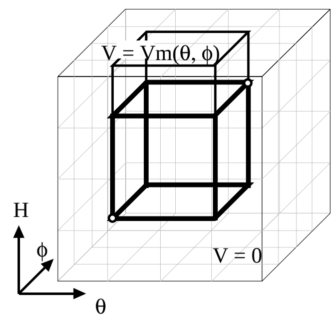

Figure 11: Real look up table which is set on memory

The volume of liquid in a vessel can be calculated by the interpolation from the elements of the LUT. The height level with volume parameter (Eq. (2)) can be obtained by searching elements which are located nearby the value of the volume then by interpolating the height level parameter of elements (Fig. 12). The over flow point of a vessel (Eq. (1)) can be obtained by the sequential search for the vertices of the polygon which expresses the mouth of the vessel. The thickness of the vessels is ignored in this system. To consider the thickness, it is necessary to make another LUT for the Eq. (4).

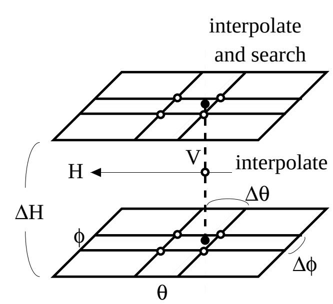

Figure 12: Method obtaining height level by volume

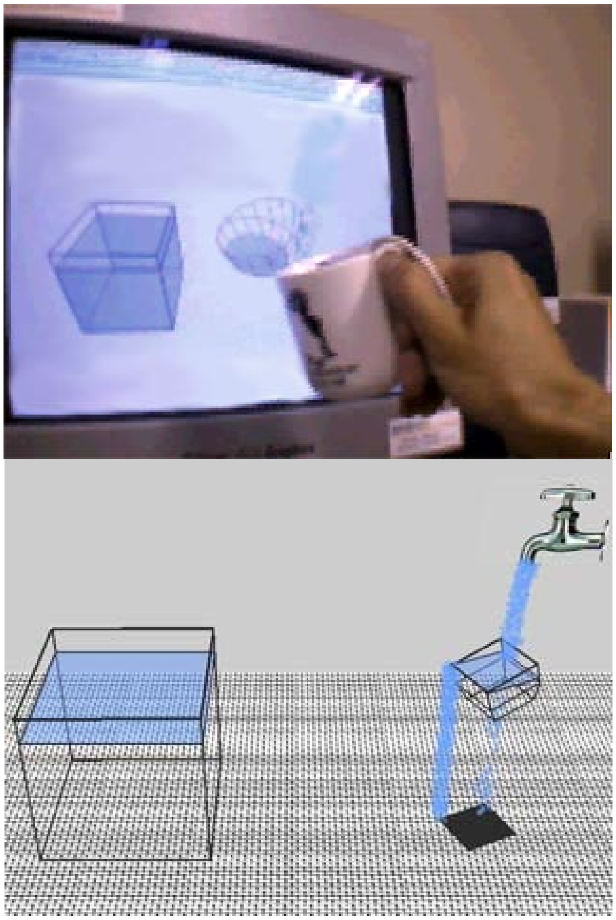

Figure 13: Appearance of proposed system

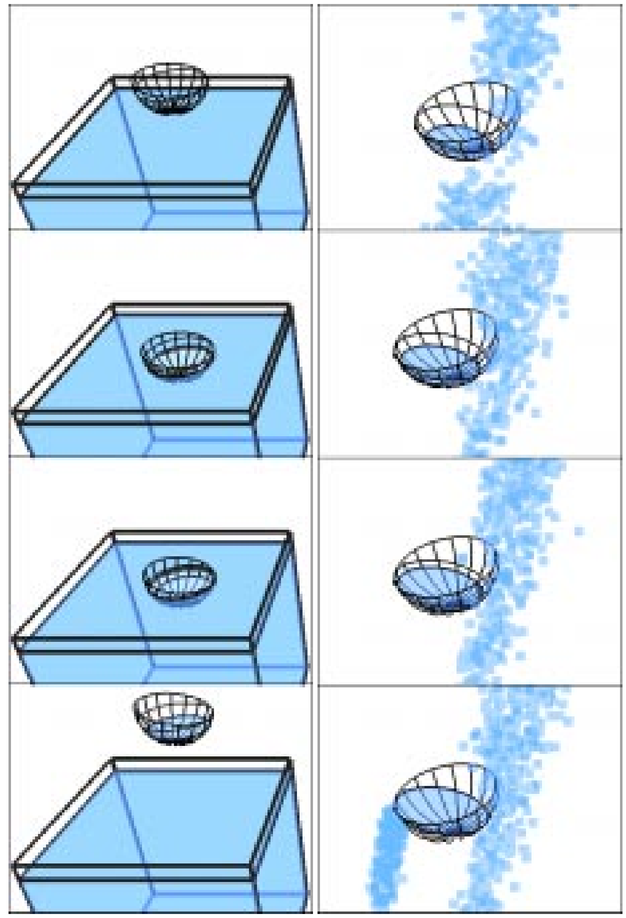

Figure 14: Manipulation of liquid using virtual vessel

Eq. (10) is used to calculate the height level of vessel 2 that is upheld by vessel 1. This system gets the height level by the following numerical method. First, the initial value of the height level of vessel 2 is set to the value that the liquid in vessel 2 does not interfered with vessel 1. Then, the height level is updated from the following Eq. until the height level of vessel 2 is converged.

$$\begin{aligned} H_{2(0)} &= h_2(\theta_2, \phi_2, V_2^{(0)}), \\ U_{21(i)} &= v_1^{+}(\theta_1, \phi_1, C_{2y} + H_{2(i)} - C_{1y}), \\ H_{2(i+1)} &= h_2(\theta_2, \phi_2, V_2^{(0)} + U_{21(i)}), i \geq 0. \end{aligned} \quad (18)$$

5. EXPERIMENTAL RESULTS

Using the model mentioned above, we implemented a system for the manipulation of the virtual liquid using virtual vessels in C language on a graphics workstation SGI OCTANE2. The exchange rate N is taken to be 10 [number of particles / cc]. In the experiment, 1 cc of the falling liquid is generated per 1 CG frame.

An example operation is shown in Fig. 13. This system gets the position and the direction of the real vessel via the motion sensor using a low-frequency magnetic field. Fig. 14(left) shows that the user can skim the liquid from another vessel. As shown in the Fig. 14(right), the user can catch the falling liquid using the virtual vessel, hold the liquid in it, then spill the liquid. In these figures, the vessel can be moved by a user and it is implemented as a hemisphere whose radius is 5 cm, and another fixed vessel is a cube whose edge length is 30 cm. Examples of manipulation using several shape vessels expressed by convex shape polyhedron are shown in Fig. 15. As shown in these figures, the user can manipulate liquid using general shape vessel in this system. This system can refresh its screen at 24 frames/sec as the average speed for the representation of around 500 particles.

Through this virtual liquid manipulation system in our laboratory, we get some positive evaluations such that “I feel that I really manipulate the water (liquid) using a cup.” The real cup with sensor is passed to users and only the fact that users can manipulate the water (liquid) in the screen using a real cup was explained to users. As the time to make users to feel that they can manipulate the liquid freely, it took 65, 75, 125, 41, 53, 42, 40, 48, 62 and 66 seconds respectively, and the average time is about 1 minute. From these results, it is considered that this system can keep the essential characteristics of real liquid manipulation. Other comments and the remained problems are as follows:

- They could recognize the feeling about the position of vir-

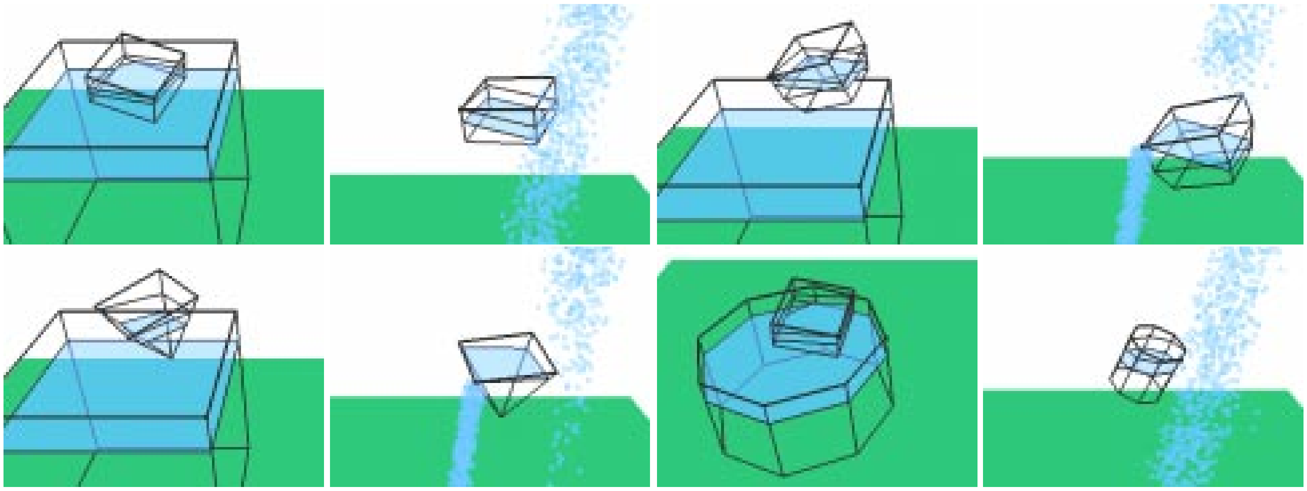

Figure 15: Examples of vessel expressed by general convex shape polyhedron

tual cup from the shadow of it, but they tend to take notice to the shadow. They are able to catch the falling liquid more easily if the shadow of each particle is drawn.

- The feeling of the movement of a virtual cup is smaller than that of the actual movement of real cup. It is difficult to keep the virtual cup (the liquid surface in it) horizontally.

For the former, introducing stereo graphics may solve the problem of the sense of depth. For the latter, a calibration is necessary to consider the size and the position of the screen. Introducing the force feedback will also be required for the representation of weight of the liquid in a vessel.

6. CONCLUSION

In this paper, we described a method for the liquid manipulation using virtual vessels which are expressed by the general convex shape polyhedron and an experimental system was implemented as a virtual reality system. Using the virtual vessel, the system can catch the falling liquid, skim the liquid from another vessel, hold the liquid and spill the liquid at an interactive refresh rate. Users have an impression close to that in the real world.

The system proposed in this paper is under the stage of the realization of the basic functions, and the following points are remained as the future subjects.

- Manipulation of the liquid using the vessels with the general concave shape.
- Interaction with the liquid under the third condition such as the water current in the river.

The addition of these functions will be required. For the former, it is considered that a concave polyhedron vessel should be divided into some neighboring convex polyhedrons. For the latter, it is considered that the third condition is represented as both particles and volume.

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