Representation of Swinging Liquid on Virtual Liquid Manipulation

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Abstract

In this paper, a model to realize an interactive manipulation of virtual liquid using a virtual vessel is described first. Then, this model is extended to represent the swinging liquid in a vessel. The liquid receives reactionary acceleration according to the acceleration of the vessel. This reactionary acceleration is considered to represent swinging liquid. Our system with this proposed model makes it possible to swing the liquid surface with swinging the vessel, then to spill the liquid with swinging it.

Key words: Virtual Reality, Interactive Manipulation, Virtual Liquid, Liquid Manipulation, Particle and Volume Model

1. Introduction

In the field of virtual reality for the recent years, the limitation is that users can manipulate only the solid objects [1], [2], [3]. While in the computer graphics technology, the scene image of water current has been represented by real-time simulation [4], [5], [6]. However, an interactive manipulation of the virtual liquid is not considered in these papers including other studies, and direct application to the interactive manipulation is still difficult.

In this paper, a model to realize an interactive manipulation of virtual liquid using a virtual vessel [7], [8] 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. Then, this model is extended to represent the swinging liquid in a vessel. The main purpose of this model is the realization of the virtual liquid manipulation, while the generation of high quality computer graphics images nor 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 swing liquid surface with swinging the vessel, then to spill the liquid with swinging it. Also the system realizes the manipulation to spill the liquid by tilting it and skim the liquid from another liquid vessel.

2. Liquid Manipulation Using Vessel

2.1 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.

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

2.2 Virtual Vessel in Virtual Space

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 parameters are 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.

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

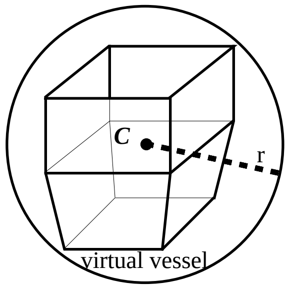

Fig. 1: Virtual vessel and a sphere including it

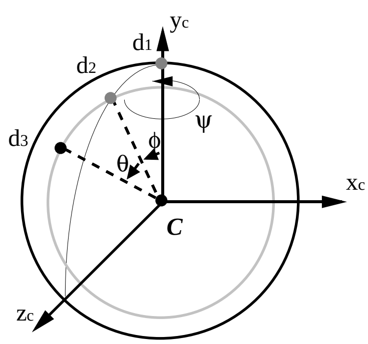

Fig. 2: Representation of tilting of virtual vessel

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 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.

2.3 Interaction Model of Liquid and Vessel

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

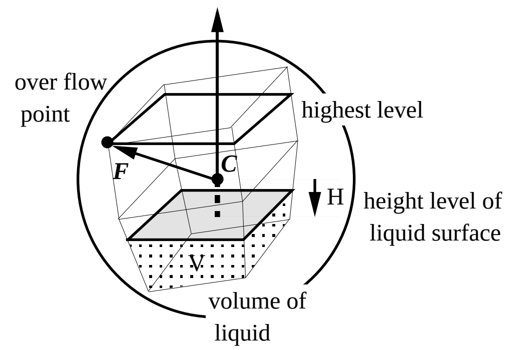

Fig. 3: Each parameter of virtual vessel

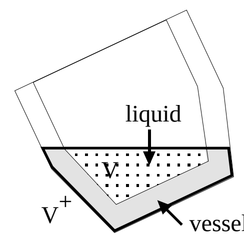

Fig. 4: Volume considering thickness of virtual vessel

2.3.1 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).

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

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

2.3.2 Liquid in Stay Condition and Vessel

In this section, we describe the interaction model between a vessel and the liquid in another vessel. 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 the equation (6) holds, vessel 1 and the liquid in vessel 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 vessel 1 under the over flow point interferes with the liquid surface of vessel 2. Then, let the volume that vessel 1 upholds the height level of vessel 2 be U. When it does not hold,

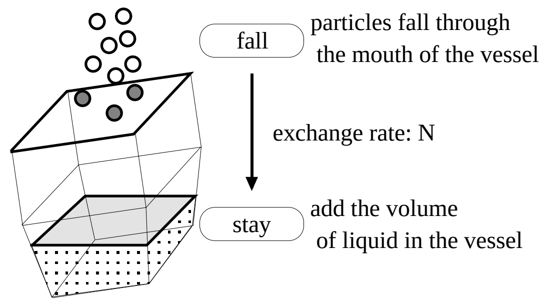

Fig. 5: Relation between two conditions of liquid (1)

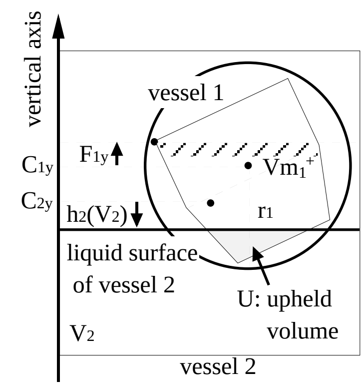

Fig. 6: Interference between virtual vessel and liquid of another vessel

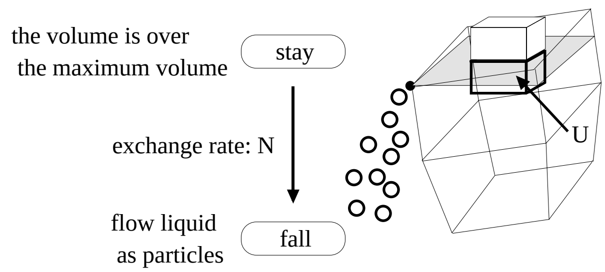

Fig. 7: Relation between two conditions of liquid (2)

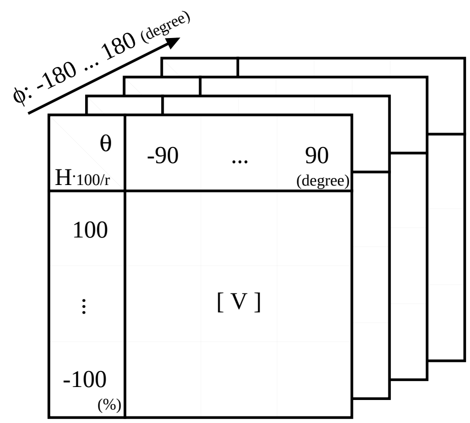

Fig. 8: Look up table for calculation volume

the situation is that the liquid in vessel 2 flows into vessel 1, the volume of the liquid in each vessel is changed with the appropriate rate [8].

2.3.3 Spilling Liquid from Vessel

When next equation holds at time t by the above interference and tilting of a vessel, the liquid spills from the vessel (Fig. 7).

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

The part of the liquid in the vessel, 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 vessel at time t is determined as

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

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

2.4 Implementation of Functions

For the implementation of a system, each function of each vessel expressed by equations (1) – (4) should be made based on the shape of each vessel respectively. In this system, each virtual vessel are expressed by a convex shape polyhedron. At loading up the shape of vessels, the LUTs (look up table) for each vessel are made to calculate the equation (3). This LUT gives V from the parameters θ, ϕ and $H \cdot 100/r$ (Fig. 8). 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 $Vm(\theta, \phi)$.

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 (equation (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. The over flow point of a vessel (equation (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 equation (4).

3. Representation of Swinging Liquid

3.1 Absolute Stay Condition

The stay condition; the condition (2) mentioned above is the absolute stay condition. The liquid surface is horizontal when the vessel is swung. However, many trial people swung the vessel vertically and horizontally at the demonstration hall of IEEE-VR2001 [9].

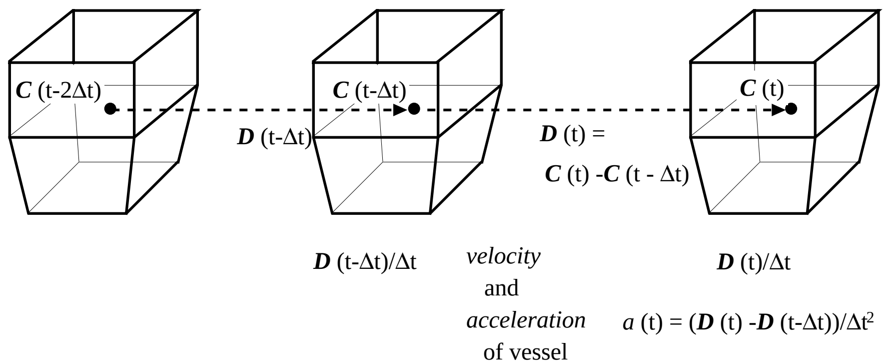

Fig. 9: Position, Velocity and Acceleration of Vessel

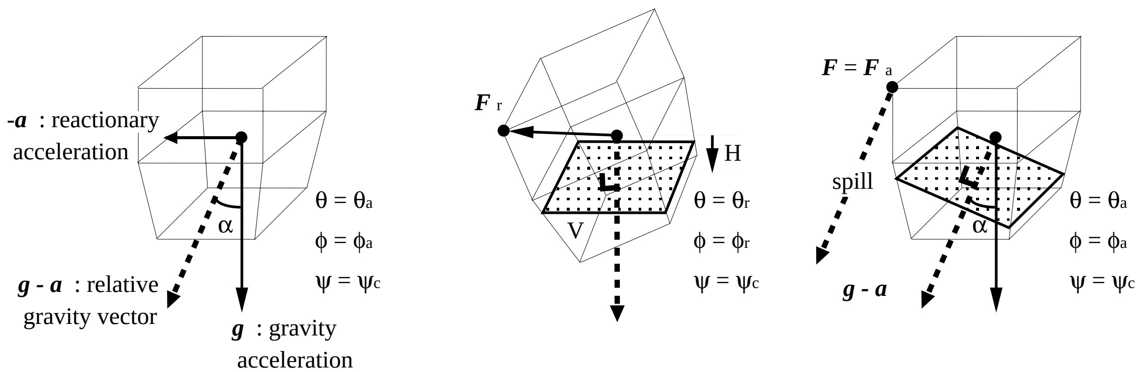

Fig. 10: Relative Stay Condition

3.2 Reactionary Acceleration and Relative Gravity Vectors

We extend the absolute stay condition to the relative stay condition for a vessel. When the position of a vessel is $C(t)$ at time t, the moving vector of its position is defined as $D(t)$ (Fig. 9).

$$D(t) = C(t) - C(t - \Delta t). \tag{10}$$

Then the velocity vector is

$$D(t)/\Delta t. \tag{11}$$

The acceleration vector of the vessel; $a(t)$ at time t is obtained as

$$a(t) = \frac{D(t) - D(t - \Delta t)}{\Delta t^2}. \tag{12}$$

The liquid in the vessel receives the reactionary acceleration $(-a)$ according to the acceleration of the vessel. The sum vector of the reactionary acceleration and the gravity acceleration is calculated as $g - a$. This vector is used to realize the relative gravity vector (See Fig. 10(left)).

3.3 Relative Stay Condition

When the direction of the vessel is

$$\theta = \theta_a, \phi = \phi_a, \psi = \psi_c, \tag{13}$$

we consider that the vessel is rotated by α as the relative gravity overlaps with the actual gravity. Then the relative direction is determined as

$$\theta = \theta_r, \phi = \phi_r, \psi = \psi_c \tag{14}$$

for the following calculations (See Fig. 10(middle)). The height level of the liquid surface is calculated by equation (2) with θ_r and ϕ_r, and the liquid surface is set up. Also the relative over flow point F_r is determined by equation (1).

Then, the vessel is rotated and returned in the direction of origin. The liquid surface is rotated with the vessel for the drawing. Also F_r is rotated to the point F_a (See Fig. 10(right)). When the liquid spills from the vessel;

$$V + U > Vm(\theta_r, \phi_r), \tag{15}$$

each liquid particle flows out from the point $F (= F_a)$ according to the relative gravity $(g - a)$.

4. 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. 11. This system gets the position and the direction of the real vessel via the motion sensor using a low-frequency magnetic field. As shown in the Fig. 12(right), the user can catch the falling liquid using the virtual vessel, hold the liquid in it, then spill the liquid. Fig. 12(left) shows that the user can skim the liquid from another vessel. As shown in Fig. 13, the user can swing liquid surface with swinging the virtual vessel, then spill the liquid. The present situation is that the surface is still flat and the representation of a wave cannot be fully performed.

Through this virtual liquid manipulation system in our laboratory, we get some positive evaluations such that “I feel that I really manipulate the 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. It is considered that this system can keep the essential characteristics of real liquid manipulation. This system can refresh its screen at 24 frames/sec as the average speed when there are about 500 particles.

5. Conclusion

In this paper, we proposed a model for liquid manipulation using virtual vessels and realized the implementation of an experimental system as a virtual reality system. Using the virtual vessel, the system can swing the liquid surface, and spill the liquid at an interactive refresh rate. Also the system can catch the falling liquid, skim the liquid from another vessel. Users have an impression close to that in the real world.

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

- Representation of the waving liquid such as the ocean surface.
- Interaction with the liquid such as the water current in the river.
- Manipulation of the liquid using the vessels with the general concave shape.

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

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Fig. 11: Appearance of proposed system

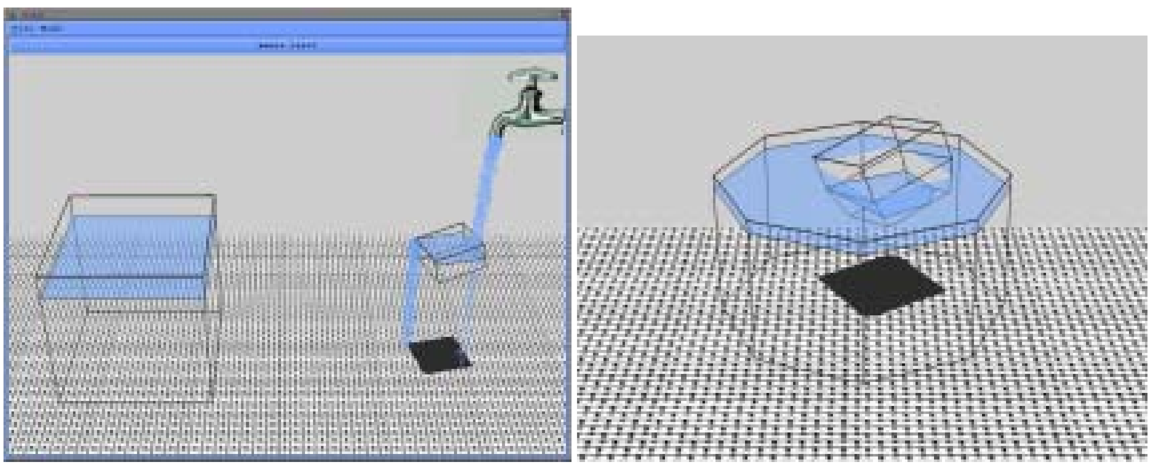

Fig. 12: Manipulation of liquid using virtual vessel

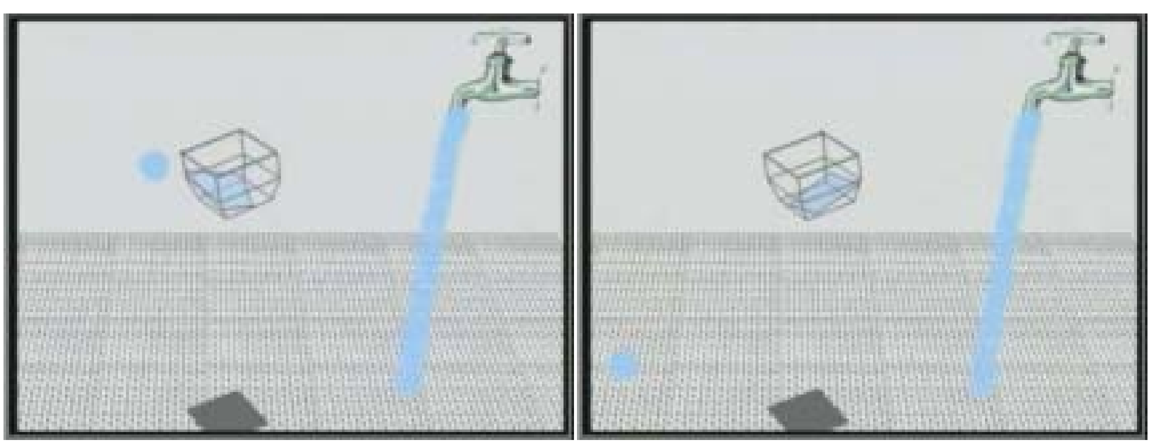

Fig. 13: Swinging liquid surface and spilling liquid