

1, 2, 3  
1 3  
2

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## Simulation Control of Simplified Fluid-Surface Model for Real-time Interaction

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가 3 가

body (rigid  
(Fluid-Surface Model)

가 PC

Keyword : Physically-based Simulation, 3D Rendering, Fluid Dynamics, Real-time Intercation

1.

(Fourier

Transform) (sin)  
(cos)

[2].

(parametric functions)

[1]

(wave)

(Computational fluid dynamics(CFD))

, 가  
[3, 4, 5]. CFD

가

( ), 가 , ,

가

(rigid body)가

(fluid)

Kass Miller Navier-Stokes equations  
2D

(Height

filed) [6]. O'Brien

(splashing fluid)

가

[7]. Kass Miller가

가

Foster 3 Navier-Stokes equations  
3 (three dimensions)

(motion)

(velocity) (shape)

[3][5]. 3D

가

(control curve)

CFD(Computational fluid dynamics)

O'Brien[4]

O'Brien

(volume

가

model), (surface model)

(spray model)

3.

3-1.

2

3

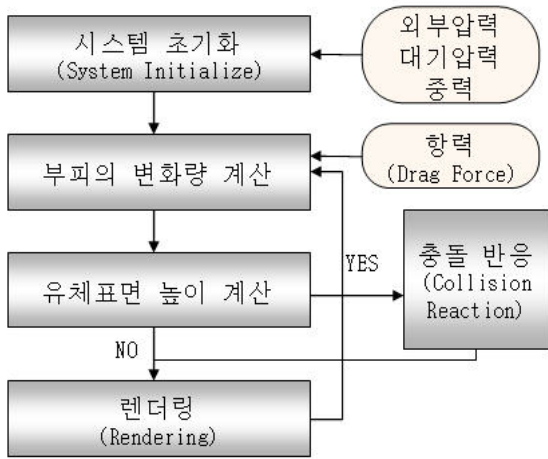
4

5 6

가

(rectilinear gird)

2.



1.

가

[7].

3-2.



2.

3

1 2

$A_1, A_2$   
 $V_1, V_2, \rho_1, \rho_2$

$A_1$

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

$$= \rho_1 A_1 V_1 = \rho_2 A_2 V_2 \quad (1)$$

가  $\rho_1 = \rho_2$  가

$$Q = A_1 V_1 = A_2 V_2 \quad (2)$$

$Q$  (flow rate)

1 2 2

1

(3)

$$\nabla \cdot (\rho \vec{V}) + \frac{\partial \rho}{\partial t} = 0 \quad (3)$$

$$\nabla = \frac{\partial}{\partial x} \vec{i} + \frac{\partial}{\partial y} \vec{j} + \frac{\partial}{\partial z} \vec{k} \quad (4)$$

$$\vec{V} = u\vec{i} + v\vec{j} + w\vec{k} \quad (5)$$

$$\nabla \cdot \vec{V} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \quad (6)$$

(3)

가

( )  $\rho$  t

$$\frac{\partial \rho}{\partial t} = 0$$

(7)

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (7)$$

3-3.

(Fluid Model)

가

(rectilinear

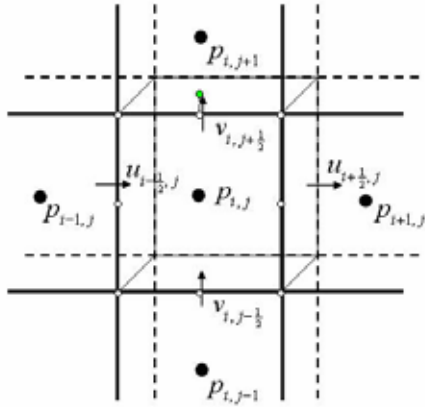
gird)

(column)

(flow)

가

( 4).



4.

(8)

[7].

$$P_{ij} = \frac{g\rho V_{ij}}{d_x d_y} = \frac{g\rho d_x d_y h_{ij}}{d_x d_y} = h_{ij} g\rho \quad (8)$$

$$[i, j] \quad d_x, d_y \quad x \quad y$$

$$, h_{ij} \quad , V_{ij} \quad , \rho$$

가 가 , [i, j]

(9)

$$P_{ij} = h_{ij} g\rho + P_0 + E_{ij} \quad (9)$$

g 가 , P<sub>0</sub> point)

(10)

V<sub>ij</sub> [7].

$$S = d_x, d_y \quad 가$$

$$h_{ij} = \frac{V_{ij}}{S} \quad (10)$$

(force) 가  
[i, j] 8 ([k, l] ∈ η<sub>ij</sub>)

$$\Delta P_{ij \rightarrow kl}$$

2

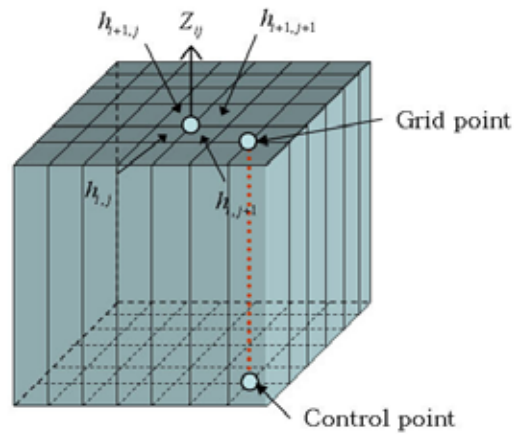
$$a_{ij \rightarrow kl} \quad (11)$$

$$a_{ij \rightarrow kl} = \frac{c(\Delta P_{ij \rightarrow kl})}{m} \quad (11)$$

c , m

$$\Delta P_{ij \rightarrow kl}$$

$$\Delta P_{ij \rightarrow kl} = \rho g(h_{ij} - h_{kl}) + E_{ij} - E_{kl} \quad (12)$$



5.

(grid point)

(control point)

가

(grid

point)

(control point)

[ 4].

(surface model)

(grid point)

(Z<sub>ij</sub>)

4

(Z<sub>ij</sub>)

5

4

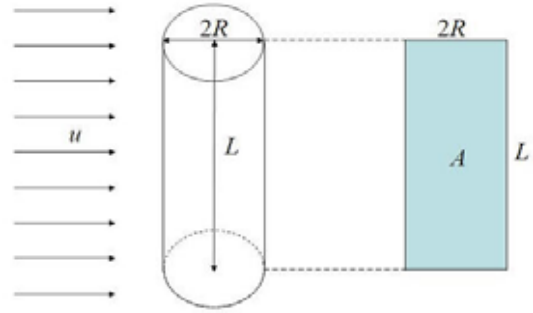
(13)

$$Z_{ij} = \frac{h_{ij} + h_{i,j+1} + h_{i+1,j} + h_{i+1,j+1}}{4} \quad (13)$$

(control point)

(14)

$$E_{ij} = -\frac{f_e}{4S} \quad (14)$$



3.  $u$  ,

$$A = 2RL$$

3-4.

$F_D$

(drag force) ,  $C_D$

(Reynolds)

(drag

가 coefficient)

1/3

가

(form drag) ,

2/3

가

가

가

(friction drag)

(shear

가

stress)

(normal stress)

가

(friction

drag)

(form drag)

3

$$u = \vec{u}$$

$\vec{u}$

( $F_d$ )

$$F_d = \frac{1}{2} C_D \rho |\vec{V}_d| S \quad (16)$$

(parameter)

가

$$F_D = C_D \rho \frac{u^2}{2} A \quad (15)$$

x, y

(Fluid-Surface Model)

4.

P4 2.0Ghz CPU, 1G  
128M OpenGL  
C++  
(texture rendering)  
19 frames/sec

가

PC

가

6

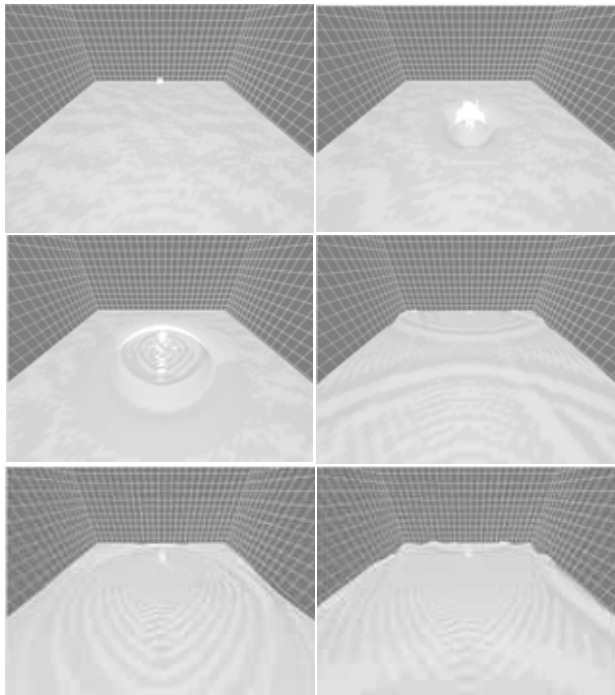
가

가

(particle)

, 3

가



6.

5.

가

6.

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