

Haptic Water; Haptics on an Animated Surface

Marcel Reuvekamp¹, Job Zwiers¹, Piet Lammertse²

¹University of Twente, Department of Computer Science, Enschede, Netherlands

²FCS Control Systems, Robotics Department, Oude Meer, Netherlands

Haptic rendering [3] is becoming an important element of multimodal interaction. Often a real-time coupling between haptics and visualization is required, based upon an underlying physical model. In this paper, we study haptic rendering and visualization of the generation of waves in shallow water. For applications, it is usually more important to come up with a believable simulation, rather than a physically accurate simulation. Therefore our focus was on obtaining suitable simplifications of the Kass-Miller model [1], and incorporation into a multimodal environment, aiming at haptic rendering and real-time visualization of waves. The result has been implemented and tested using a Haptic Master device, produced by FCS Control Systems [2].

1 Introduction

Recently, haptic research has been rapidly growing. Lots of nice demos can be found that use a haptic device of any kind. Most demos however show a static virtual environment; you can really feel the objects in the virtual world, but you can't change the appearance of them. This demo is different; it shows a virtual environment with a little pool of water, which can produce shallow waves. These waves can be generated by throwing in an object, which is coupled to the haptic device. In our case the haptic device is a FCS Haptic Master, a haptic device based upon admittance control.



Fig. 1. The FCS Haptic Master

The simulated object really flows upon the water surface and thus has the swells of the shallow waves. The more you move the Haptic Master in the water, the more ferocious the shallow waves become.

The real challenge was not to create waves that just look convincing from the visual point of view, but rather to let the user believe that he is holding a floating object in his hands, and to couple the haptic feedback and the visual feedback. The forces that we're dealing with aren't steady, but change with the movement of the water and the amount of submersion of the object.

2 Water Animation

The animation of the water is based upon a derivation of the shallow water model of Kass and Miller [KAS90]. This model is in essence a finite element simulation based upon a simplification of the full Navier-Stokes model. The simplifications were necessary in order to obtain a satisfactory real-time behaviour for haptic feedback. The water is modelled by means of a height field, where each cell has a direct influence on its adjacent cells. These influences are based upon an epsilon-value. All in all the final formula becomes:

$$h_{i,j}(n) = h_{i,j}(n-1) + (1-t) \left(\begin{array}{c} h_{i,j}(n-1) - h_{i,j}(n-2) + \\ \left(\begin{array}{c} -6h_{i,j}(n-1) + \\ h_{i-1,j}(n-1) + h_{i+1,j}(n-1) + \\ h_{i,j-1}(n-1) + h_{i,j+1}(n-1) + \\ \frac{1}{2} \left(h_{i-1,j-1}(n-1) + h_{i+1,j-1}(n-1) + \right. \\ \left. \frac{1}{2} \left(h_{i-1,j+1}(n-1) + h_{i+1,j+1}(n-1) \right) \right) \end{array} \right) \end{array} \right) \quad (1)$$

$$e = g (\Delta t)^2 \left(\frac{d}{(\Delta x)^2} \right) \quad (2)$$

where n represents the time, t the amount of damping in the water, g the gravitational constant, Δt the time step, d the constant depth of the water in rest and Δx the size of a cell.

Since the Navier-Stokes equations have the tendency to get unstable when using too large or too small parameters, a bit of experimenting was necessary to determine the parameters for the calculation of the epsilon-value.

2.1 Interaction with an object

Shallow waves will occur when a certain cell is heightened or lowered. If you want the water to react to the object coupled to the Haptic Master, it is possible to calculate the amount of submersion of the object. If the object is being pushed in the water, extra volume is being put in the pool, so the cells that cover the object need to be

heightened with a certain calculated amount. If the object is being pulled out of the water, volume is being pulled from the pool, so the cells that cover the object need to be lowered with a certain calculated amount.

3 The Haptic Forces

A couple of forces need to be modelled for this demo:

- the gravitational force
- the viscous force
- the upward force

3.1 The Gravitational Force

The gravitational force is probably the simplest. It is just a constant force pointed downwards. The magnitude of this force is constant and based upon the gravitational constant and the mass of the object.

3.2 The Viscous Force

The viscous force again is pretty straight forward. It can easily be made by adding a damper-object to the demo. The amount of damping is based upon the amount of submersion of the object.

3.3 The Upward Force

The upward force is more difficult. It is based upon the volume of the object, the density of the water and the volume of the object that is submerged. This force is implemented by two springs, with a deadband greater than the Haptic Master's workspace, to prevent oscillation. Both of the springs have the same spring constant and deadband. However they differ in direction and position. One spring pulls the Haptic Master towards it and the other one pushes the Haptic master away from it. The vertical positions of the springs differ exactly the height of the object. The pulling spring's origin is exactly this height above the pushing spring's origin. The pulling spring starts to work as soon as the object touches the water and the pushing spring starts to work as soon as the object is completely submerged. With this construction, the pushing spring's extra stretch compensates the extra stretch of the pulling one so the net maximum upward force is constant. After a little of billowing a balance will be reached where the spring constant multiplied with the stretch of the pulling spring equals the gravitational force.

Little waves will form when submerging the object. So the water height will change. You can calculate the velocity with the wave height changes and simply pass this velocity to both of the springs, so the origins of the springs change and it seems as though the object flows on the water surface.



Fig. 2. A screenshot of the Haptic Water demo

4 Conclusion

Using approximate finite element simulation of waves in shallow water, based upon the Kass-Miller model, allows for believable haptic rendering combined with visually attractive feedback in real-time.

References

1. Kass, M., Miller, G. "Rapid, Stable Fluid Dynamics for Computer Graphics in Computer Graphics", Vol 24, No. 4, (1990) 49-55
2. FCS Control Systems: HapticMASTER User Manual, Version 2.0 (2002)
3. Zilles, C.B. and Salisbury, J.K., "A constraint based god-object method for haptic display", Proc. IEEE/RSJ Int. Conf on Intelligent Robots and Systems, Pitt. PA, 146-151, 1995.