Sculpting Fluids:
A New and Intuitive Approach to Art-Directable Fluids

Tuur Stuyck *
KU Leuven

Philip Dutré
KU Leuven

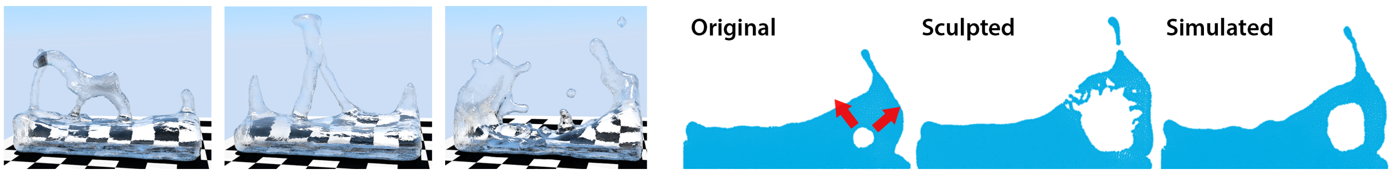

Figure 1: *Left: 3D examples of sculpted fluids. Right: Didactic 2D example of the fluid authoring process.*

Abstract

Fluid simulations are very useful for creating physically based water effects in computer graphics but are notoriously hard to control. In this talk we propose a novel and intuitive animation technique for fluid animations using interactive direct manipulation of the simulated fluid inspired by clay sculpting. Artists can simply shape the fluid directly into the desired visual effect whilst the fluid still adheres to its physical properties such as surface tension and volume preservation. Our approach is faster and much more intuitive compared to previous work which relies on indirect approaches such as providing reference geometry or density fields. It makes it very easy, even for novice users, to modify simulations ranging from enlarging splashes or altering droplet shapes to adjusting the flow of a large fluid body. The sculpted fluid shapes are incorporated into the simulation using guided re-simulation using control theory instead of simply using geometric deformations resulting in natural-looking animations.

Keywords: Fluid Control, Direct Manipulation

Concepts: •**Computing methodologies** → *Physical simulation;*

1 Overview

Physics-based animation has become an important tool in computer graphics and is essential in recreating realistic looking natural phenomena. Developers have been looking for tools to control simulations that allow artists to modify the simulation to best suit the artistic requirements. However, the complexity and non-linearity of the Navier-Stokes equations make fluid simulations notoriously hard to control. This is caused by the chaotic nature of the Navier-Stokes equations: small changes in simulation parameters can produce very different results which makes it very challenging to achieve a specific target animation. Even for experienced animators multiple time-consuming trial-and-error iterations are required in order to achieve satisfying results. Our system enables novice users to create art-directed fluid simulation with little effort.

Previous work uses either geometric deformations [Pan et al. 2013] or reference meshes [Shi and Yu 2005] and [Raveendran et al. 2012] to obtain controlled simulations. Even though these methods provide impressive results, the fluid authoring process remains indirect and cumbersome for artists.

We present an approach to significantly decrease the time spent on fine-tuning fluid animations. Our method incorporates a direct manipulation phase of the fluid in which the animator can adjust the simulation interactively. The simulation can be easily tuned to artistic needs by clicking and dragging the fluid to the desired goal position. This hides the complexity of the underlying simulation from the artists. The three leftmost images of Figure 1 show stills from an animation edited with our system where different shapes of fluid splashes are exhibited that are unlikely to occur spontaneously.

Our method adjusts a regular fluid simulation by performing two additional phases, the sculpting phase and the control phase and can be fitted into any particle-based fluid solver.

1. During the *manipulation phase*, the fluid body is sculpted and the resulting shape is stored as a keyframe to be used as the goal position for the subsequent control phase.
2. In the *control phase*, the simulation is loaded at a user-defined time before the desired keyframe and the simulation restarts with every particle equipped with a controller to guide it towards the keyframed position.

2 Sculpting the Fluid

Our proposed workflow is inspired by tools such as ZBrush[1] and Mudbox[2] which allow to model 3D geometry similar to clay sculpting. This makes it much more convenient compared to pushing individual vertices around and other traditional approaches.

During the manipulation phase, fluid deformation is achieved using vector field based shape deformations [von Funck et al. 2006] determined by mouse movements. However, simply applying the deformation may lead to unrealistic and physically impossible shapes because the deformation does not take into account the physical properties of fluids. In order to achieve a plausible

*tuur.stuyck@cs.kuleuven.be

SIGGRAPH '16, July 24-28, 2016, Anaheim, CA,
ISBN: 978-1-4503-4371-8/16/07
DOI: http://dx.doi.org/10.1145/2945078.2945089

[1]https://pixologic.com/
[2]http://www.autodesk.com/products/mudbox/overview

fluid configuration, this deformation technique is combined with a relaxation scheme which allows the fluid to relax locally when being deformed. High pressure differences are smoothed and surface tension provides typical fluid-like behavior such as drops and rounded boundaries. This increases the intuitiveness of the method and plausibility of the resulting animations. Figure 2 shows an example of the sculpting process.

We perform fluid relaxation using a symmetrical adaptation of the double density technique proposed by Clavet et al. [Clavet et al. 2005] in combination with a surface tension technique from Becker et al. [Becker and Teschner 2007]. The relaxation is a standard fluid update step with all particle velocities set to zero and without applying body forces.

(a) *Original* **(b)** *Deformed* **(c)** *Relaxed*

Figure 2: *Example of sculpting a fluid.*

3 Controlling the Fluid

During the second step of our algorithm, the control phase, the positions of the particles stored in the keyframe are used as goal positions for the controllers. In order to introduce the keyframe into the simulation, we recompute s frames prior to the keyframe during which all the particles are augmented with a controller that computes an appropriate force to guide it towards its goal position stored in the keyframe. We opted for a proportional and integral controller (PI) for its simplicity and efficiency. Results of the control process are shown in Figure 3.

This type of PI control requires very little computation time and produces convincing results when initialized with the appropriate controller settings. More complex optimal control such as model predictive control can also be used. This computes the optimal forces over a sequence of time in the future to make sure that the keyframes are reached at the appropriate times.

(a) *Original* **(b)** *Sculpted* **(c)** *Simulated*

Figure 3: *Example of a simulation using a sculpted fluid shape as a keyframe.*

4 Discussion

Our approach has the advantage of making complete abstraction of the underlying math and physical parameters, benefitting artists greatly as they can focus on the story telling without spending time fine-tuning the initial state and physical values. The direct manipulation of fluids results in significantly easier and faster fluid simulation authoring which produce the expected results without a painstaking trial-and-error process. Artists need very little training using the system because the workflow of setting fluid keyframes is the same as with traditional computer animation.

	Score	**Median**
1 I found the method intuitive to use	4.3 ± 0.5	4
2 I think the sculpting approach is capable of modeling keyframes	4.2 ± 0.4	4
3 I think that I would be able to author simulations faster using this software	4.7 ± 0.5	5
4 I found the results predictable	3.9 ± 0.6	4
5 I need to understand the equations in order to use this software	1.1 ± 0.3	1
6 I found the experience enjoyable	4.1 ± 0.9	4
7 The relaxation algorithm is helpful	4.3 ± 0.7	4

Table 1: *General application evaluation: average scores with standard deviation and median score. Scores can range between 1 and 5.*

Additionally, since it requires no change to the standard fluid simulation algorithm it can be used in combination with other extensions such as multi-resolution particles. We verified this using a user study. We obtained a SUS score of $83/100$ with a standard deviation of $\sigma = 6$ which shows the high perceived usability of our system. Additional results can be found in Table 1.

The main limitation of the method is that the user needs to find a good value for the controller strength in order to reach the keyframe at the desired time. However, this limitation would be alleviated by using optimal control theory. We presented the method using 2D examples for clarity but the algorithm is easily implemented in 3D, see Figure 1 for some example three-dimensional fluid shapes created with our system.

References

BECKER, M., AND TESCHNER, M. 2007. Weakly compressible sph for free surface flows. In *Proceedings of the 2007 ACM SIGGRAPH/Eurographics symposium on Computer animation*, Eurographics Association, 209–217.

CLAVET, S., BEAUDOIN, P., AND POULIN, P. 2005. Particle-based viscoelastic fluid simulation. In *Proceedings of the 2005 ACM SIGGRAPH/Eurographics symposium on Computer animation*, ACM, 219–228.

PAN, Z., HUANG, J., TONG, Y., ZHENG, C., AND BAO, H. 2013. Interactive localized liquid motion editing. *ACM Transactions on Graphics (TOG) 32*, 6, 184.

RAVEENDRAN, K., THUEREY, N., WOJTAN, C., AND TURK, G. 2012. Controlling liquids using meshes. In *Proceedings of the ACM SIGGRAPH/Eurographics Symposium on Computer Animation*, Eurographics Association, 255–264.

SHI, L., AND YU, Y. 2005. Taming liquids for rapidly changing targets. In *Proceedings of the 2005 ACM SIGGRAPH/Eurographics symposium on Computer animation*, ACM, 229–236.

VON FUNCK, W., THEISEL, H., AND SEIDEL, H.-P. 2006. Vector field based shape deformations. In *ACM Transactions on Graphics (TOG)*, vol. 25, ACM, 1118–1125.