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Recent Progress in Flow Visualization Techniques toward the Generation of Fluid Art

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Abstract : This paper describes recent progress in flow visualization techniques from the viewpoint of visual art incorporating fluid motion. The images of fluid art introduced here are categorized into four groups: the reflected or refracted patterns of free surface motion in nature and in a controlled environment, the coherent turbulent phenomena of fluid flow, and the fluid motion induced by the physical properties of fluids. It is shown that flow visualization techniques, which were originally developed in the field of engineering, have been successfully applied to the creation of artistic images.

Keywords : Flow Visualization, Fluid Art, Visualization Technique, Scientific Art.

1. Introduction

Engineering flow visualization has been carried out to explore physical mechanisms of fluid motion in industrial fluid mechanics. Such visualized flow images provide a useful tool for understanding fluid mechanics, but from the visual arts perspective, we often find these images aesthetically pleasing. Researchers in the field of fluid mechanics have often encountered beautiful and fascinating images in the course of their flow visualization studies. Typical examples of such flow visualization pictures can be found in the literature (Van Dyke, 1982; Flow Visualization Soc. Japan, 1990; Saminy et al., 2003). Thus, researchers have developed many experimental techniques for engineering flow visualization, which were not initially created for artistic purposes.

In recent years, the unification of art and science by the advancement of computer technology and digital visualization techniques has been a topic of interest. Thus, digital art in combination with advanced visualization technology is becoming popular in the art community, so that the roles of artist and scientist have become less distinct than before. Recent progress in the overlap of science and art was discussed at the 4th International Symposium on Science and Art (New Jersey, 2005). Scientists and artists presented recent research results and their artistic results, but there were very few collaborative works between them. More detailed information can be found in the preprint of the symposium proceedings. It is expected that future collaboration among scientists and artists will be more fruitful for the further development of art and aesthetically driven science. At present, there is little work specifically contributing to visualization techniques for the generation of fluid art.

The purpose of this paper is to introduce some examples of arts created from fluid motion, which are categorized into four groups based on flow phenomena and visualization techniques: free surface visualization with reflection or refraction, both in nature and in a controlled environment, buoyancy-driven phenomena of turbulence visualized with dyes and tracers, and fluid property-driven flows visualized with dyes.

2. Fluid Arts and Flow Visualization Techniques

2.1 Fluid Art Using Free Surface Motion in Nature

The reflection and refraction of light occurs at the interface of fluids, such as water and air. When the fluid interface is in chaotic motion, the incidence angle of light changes spatially in the target area of flow visualization. Thus, the reflection and refraction occurs locally in the target image, which often creates a beautiful image for fluid art (Verhoeckx, 2005 a, b).

Looking through the viewfinder of the camera at the reflection of the city of Amsterdam on the canal's surface, a beautiful pattern of color in motion can be seen. Within each frame, the structures appear to be dependent on currents, as well as dependent on the reflection of, for example, a passing cyclist in a red coat, the blue curtains of a houseboat, the foliage of a nearby tree and bricks of the buildings that line the canal. One second of image acquisition data is comprised of 25 still images, which can be used to study the interaction of water and light and the changes in motion. Figure 1 shows two successive images from these 25 frames. These tiny events revealed an entire trajectory of changes, which enabled the flowing movement to be read in a whole new way. The fragments not only disclosed the hidden events more exactly but, when brought together in a collage, these 'one-second stories' took on a poetic resonance.

Figure 2 shows a double print of the image of the water surface artificially interacting with the light from the moon. By combining the two images the artist used the reflection of the events on the water surface to create a new work of art. Using the digital techniques of the editing suite, it is possible to speed things up, use slow motion, make the viewer look back in time using flashbacks, split time, make jumps in time and stop time by freezing the image and bringing motion to a standstill. The water surface intrigues the artist because of its various states, the unpredictability of its movements and its interaction with light. Due to its refraction of light, the surface also has the capacity to reflect and transform images. This distortion results in a certain degree of abstraction,

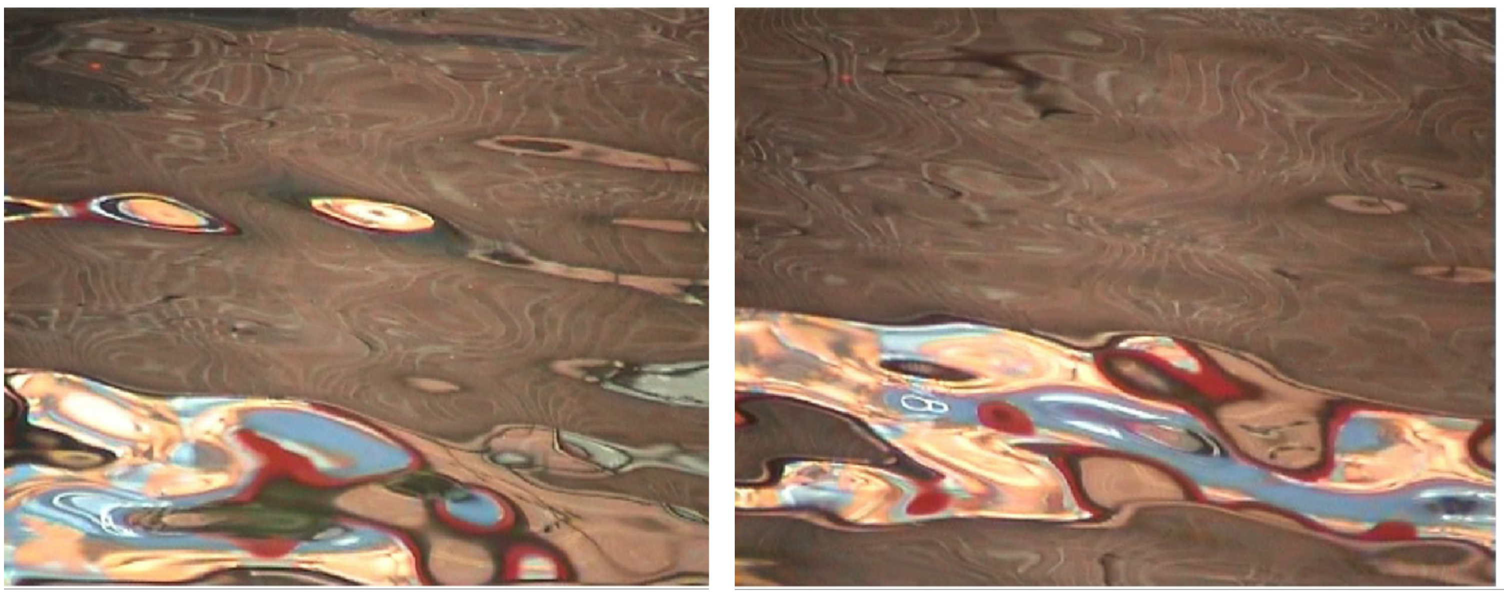

Fig. 1. Still images from a 1 second video, imaged from Leidsegracht a street in Amsterdam 2005.

which strengthens the image's power of expression. Water seems to behave as an artist in its own right, as its motion 'paints' with light as if mixing watercolor.

Exploring the events on the free water surface over time is an art project in progress. The artist is seeking exchange and collaboration with scientists intrigued by events which cannot easily be observed by the naked eye. How can, for instance, the trajectory of the patches of light be conveyed in addition to the artistic expression of light form and motion? The intent of this work is to show that art can contribute towards a form of recognition and that the combination of the two points of view, that of the scientist and the artist, will lead to a stronger and more comprehensive concept of what happens in the reflection of light on the water surface over time.

Fig. 2. Still image from the silent film “Heavenly Bodies” 2003, the water surface artificially interacting with the light from the moon.

2.2 Fluid Art Using Free Surface Motion in a Controlled Laboratory Environment

Beautiful fluid art can also be created within a laboratory environment. By placing a lens at its focal length's distance away from a diffuse white light source that is covered with a planar transparent color palette (see Fig. 3), a system of parallel color beams will emerge, where the beams of each particular color will be parallel to each other, but will be oriented in a different direction with respect to the beams of other colors. When this system of parallel color beams illuminates a free surface, only a particular slope of the free surface will reflect (or refract) a particular color towards the observer. In this manner, a one-to-one correspondence between color and the free surface slope is developed. Figure 4 shows the experimental setup for imaging reflected light from a free surface, though variations of this setup have also been used to image refracted light as well. Details of this methodology can be found in Dabiri et al. (1997). Due to the one-to-one correspondence between color and the free surface slope, the deformation of the free surface will selectively reflect (or refract) different colors towards the observer, producing images that can be scientifically evaluated to determine the free surface's slopes, while being equally beautiful from a fluid art perspective. For scientific purposes, the color palette should contain as many bright colors as possible, since bright colors will result in images containing good signal-to-noise ratios, while the availability of more colors allows for much better color and hence slope resolution.

The color palette shown in Fig. 3 and the experimental setup shown in Fig.4 have been used to generate the images shown in Fig. 5 and Fig. 6. Figure 5 is the result of imaging a free surface of water that is distorted by a combination of near surface turbulence and random surface wave patterns, while Fig. 6 is the result of imaging a free surface that is distorted by traveling surface waves over a vortex that is connected with the free surface. While bright continuous color palettes are desirable for scientific purposes, from an artistic perspective, the reader is encouraged to experiment with different types of color palettes, which might incorporate discontinuous as well as dim colors, in order to elicit different artistic effects.

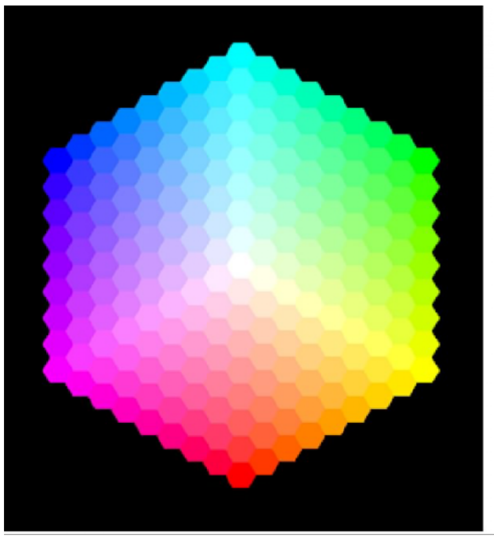

Fig. 3. Color palette.

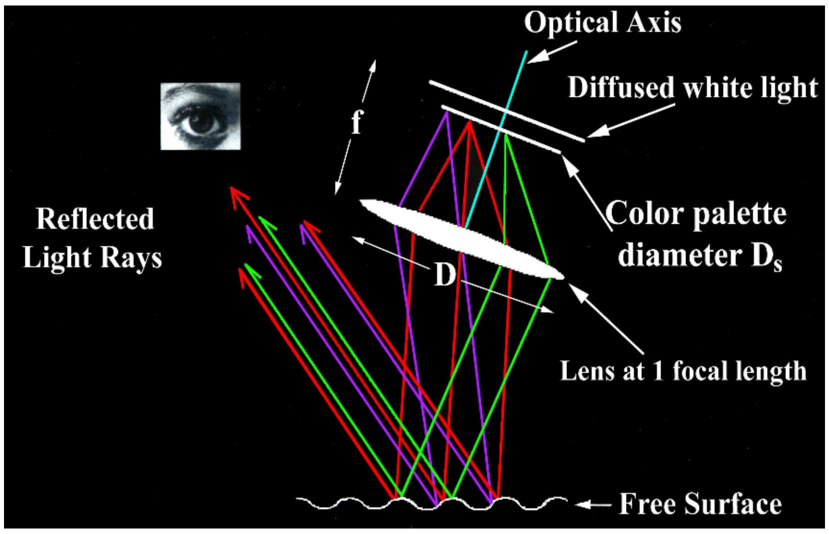

Fig. 4. Experimental setup for the reflective mode.

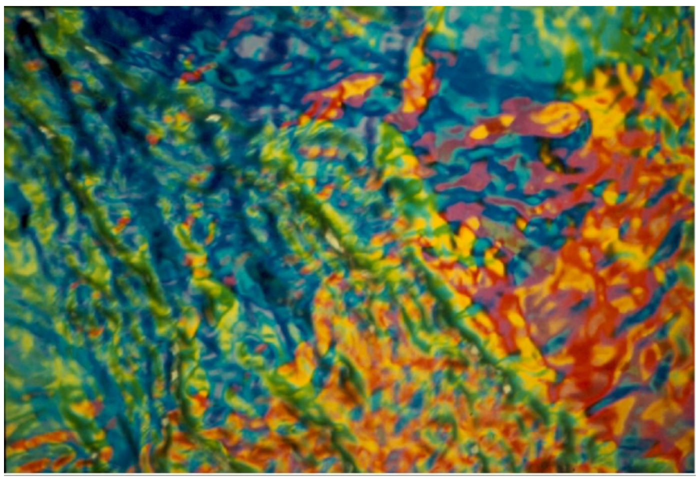

Fig. 5. Free surface distorted by near surface turbulence and random surface wave patterns.

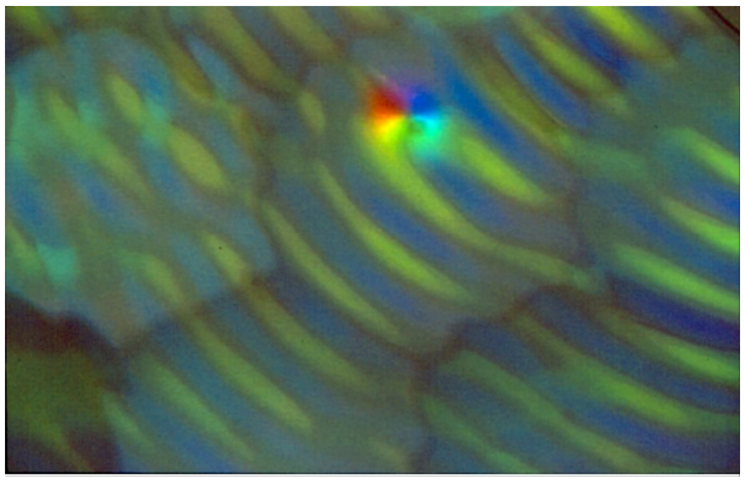

Fig. 6. Free surface distorted by traveling surface waves over a vortex.

2.3 Fluid Art Using Turbulent Fluid Flow Phenomena

When a working fluid of higher temperature issues from the bottom of still fluid of lower temperature, a plume is generated due to the buoyancy of the fluid. In the turbulent state, three-dimensional fluid motion is formed at the interface of the plume and the still surroundings, and the motion becomes random in space and time, forming vortices along the interface (Funatani et al., 2004). Using a laser-induced fluorescent technique, the vertical cross-sectional view of the plume structure is visualized using illumination using an Ar laser sheet (Fujisawa and Watanabe, 2005; Watanabe et al., 2005). Note that Rhodamine B dye is added to the fluid of the plume for visualization purposes. The resulting image of fluid motion is shown in Fig. 7 (with permission by Y. Watanabe). Such an image registers a range of orange colored light intensity, which is roughly proportional to the dye concentration and the illumination intensities. It is seen that the large eddy structure generating from the plume increases in size, while the fluid velocity decreases with distance from the plume source. The light and darkness of the plume structure move upward with a beautiful meandering motion, which also contributes to the artistic image.

A beautiful pattern of turbulence can be seen in the natural convection of a horizontal fluid layer heated from the bottom, as shown in Fig. 8 (with permission by M. Watanabe). The convection pattern studied in this work is a non-penetrated thermal convection, where the lower boundary is heated from below and the upper boundary is adiabatic (Fujisawa and Adrian, 1999). Since the flux Rayleigh number is very large $R_{af} = 6.5\times10^8$, the polygonal spoke structure appears near the heated surface in a turbulent state, which is due to the buoyancy driven instability. The flow visualization was carried out using temperature-sensitive liquid-crystal tracers with horizontal illumination using white light sheet. Note that the liquid-crystal tracers (10 μm in diameter) change color from red through green and blue to violet as the temperature of the fluid increases (Menard et al., 2006). Thus, the higher temperature area prevails along the spoke with a red color and the lower temperature area appears in the convection cell as green. The selection mechanism of shape and size of the spoke structure is of fundamental interest in fluid mechanics, but the harmony of blue and red color contributes to the beauty of fluid art.

Although these turbulent phenomena have been seen in a controlled laboratory environment, they can also be observed in natural environments, such as black smoker-type hydrothermal plumes in the seafloor (Bemis et al., 2002) and thermal convection in the atmosphere. However, the optical access can range from easy to quite difficult for such natural phenomena. Thus, flow visualization in a controlled laboratory environment provides a useful tool for the creation of fluid art, too. It should be mentioned that clouds are often selected as natural phenomena for fluid art due to easy access to the phenomena (Hertzberg and Sweetman, 2005).

Fig. 7. Structure of turbulent buoyant plume.

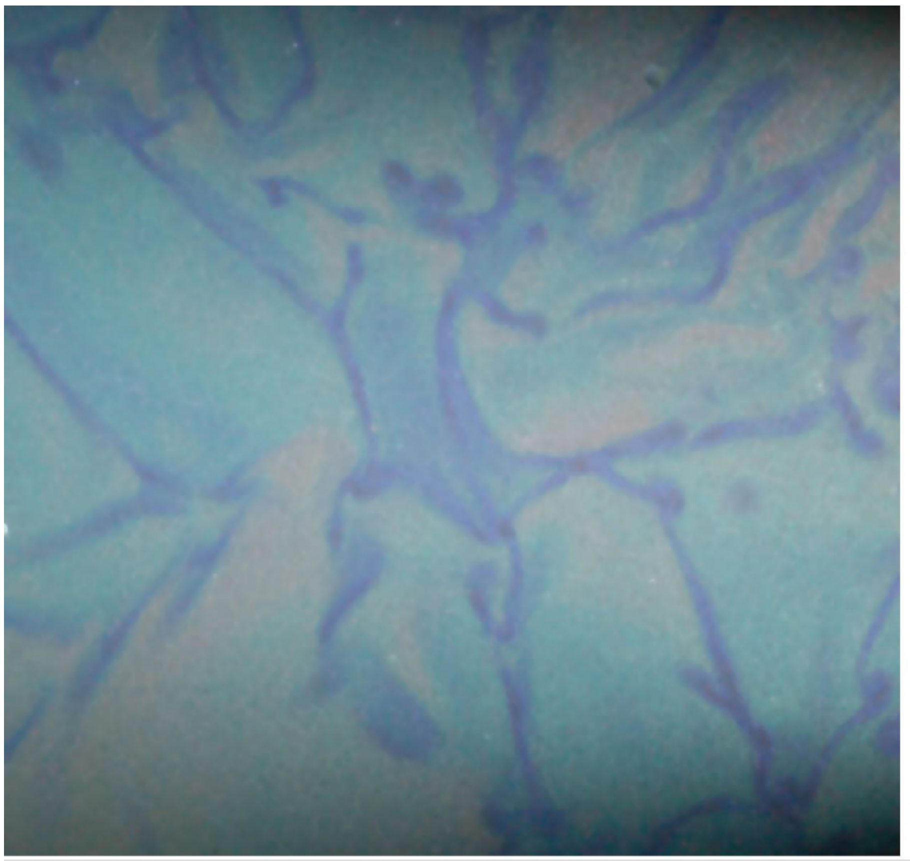

Fig. 8. Spoke structure over a heated surface of non-penetrative thermal convection.

2.4 Fluid Art Using Physical Fluid Properties

In this case the fluid motion is driven by the nature of fluid properties such as density, viscosity, surface tension and so on. A unique fluid art can be generated using such combinations of fluid properties. Figure 9 (used with permission by B. Hayworth) shows an interesting instability. When blue food coloring, consisting of water, propylene glycol and dye is placed in contact with a 2 cm oval pool of corn syrup on a white ceramic plate, a wavy pattern is generated. The food coloring reduces the surface tension of the syrup, which flows in the direction of the coloring, while pulling the food coloring up onto the top surface. At the same time, the greater density of the coloring provides a downward force; the competing effect drives the unstable interface.

Figure 10 (used with permission by T. Read) demonstrates inverse physics, due to the hydrophobic force between oil and water. Initially, thin layers of dilute, dyed isopropyl alcohol above vegetable oil were pressed between two flat, horizontal plates of glass and viewed from above. After the top plate of glass was slid off, the alcohol sheet began beading up at the edges, and the beads began to drain off to the side. Similar to Fig. 9, the unstable interface demonstrates a periodicity, resulting in a regular pattern.

These images were generated in the context of a course on the art and physics of flow visualization. Additional images and techniques are presented in Hertzberg and Sweetman (2005).

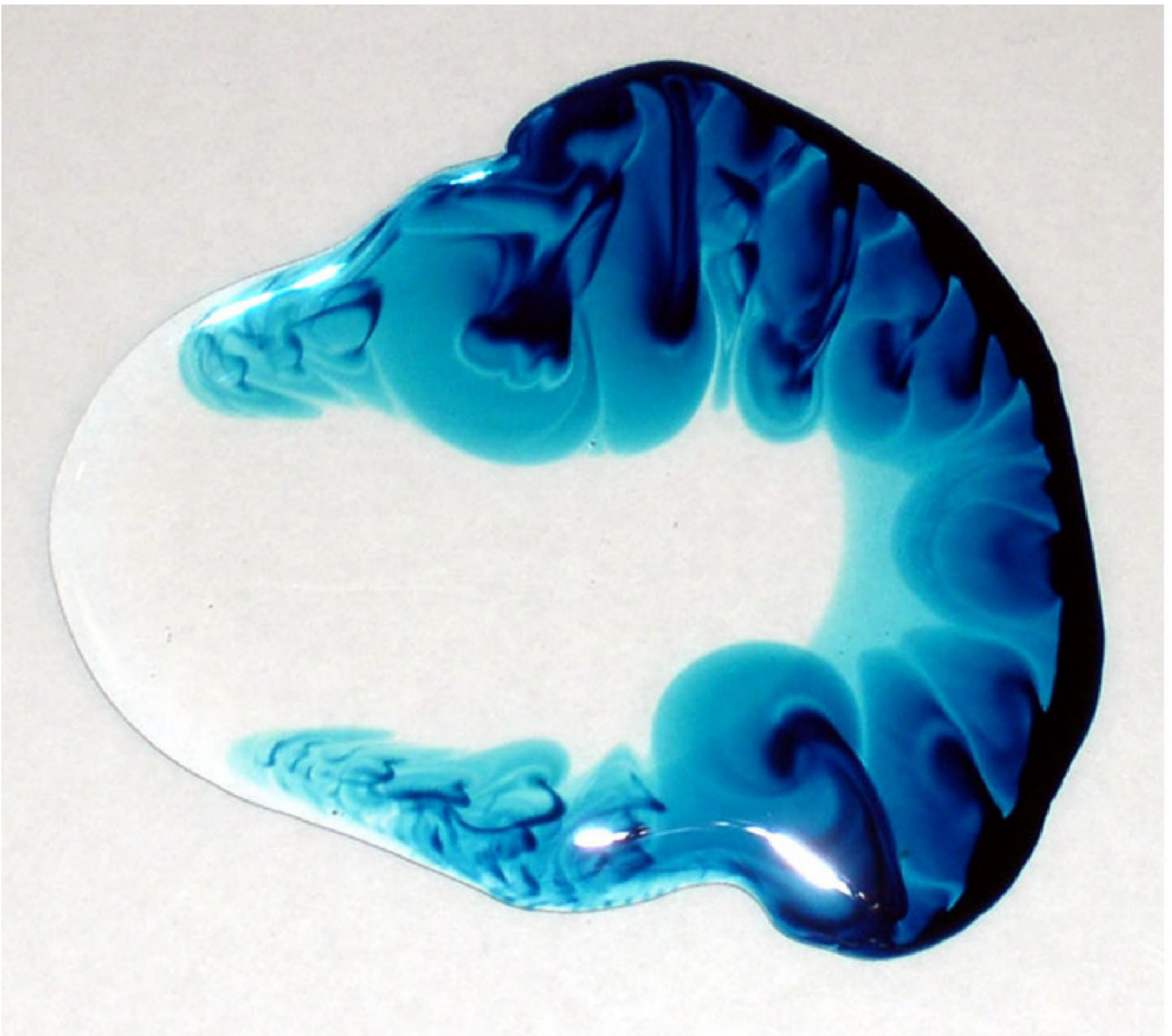

Fig. 9. Fluid art generated by a surface tension instability.

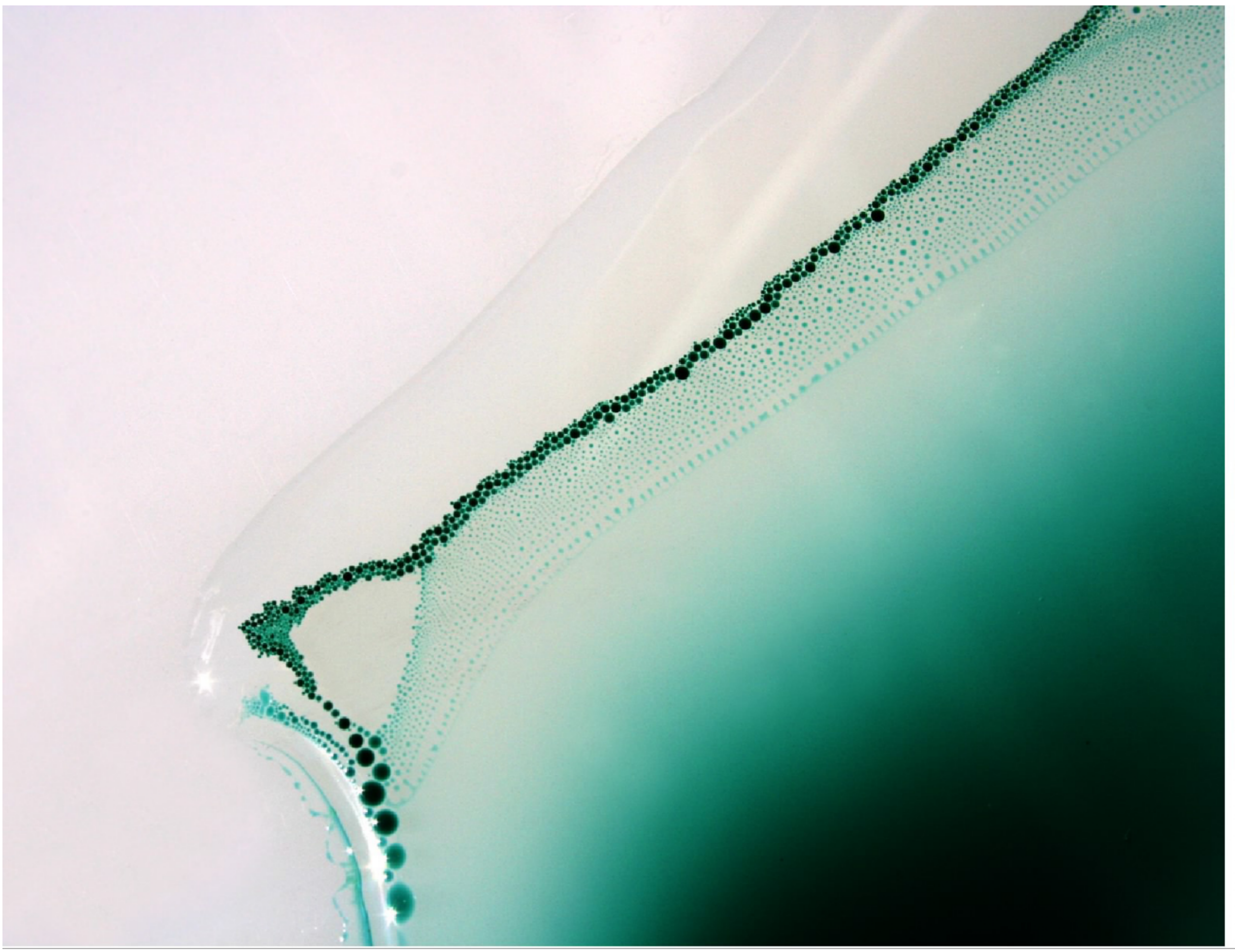

Fig. 10. Fluid art generated by hydrophobic forces between oil and water.

3. Conclusions

Recent progress of visualization techniques in visual art is described for the creation of fluid art. The fluid arts introduced here were categorized into four groups, which included the reflection or refraction pattern on the free surface motion in nature and in a controlled laboratory environment, the coherent fluid motion of turbulence, and the fluid motion induced by physical fluid properties. The explanation of flow physics and the visualization techniques are described for further development of fluid art.

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Author Profile

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Dana Dabiri: He is an Assistant Professor at the Department of Aeronautics and Astronautics at the University of Washington, since 2002. His interests are to develop new and advanced quantitative flow imaging techniques to study fundamental fluid flows such as turbulence, mixing, vortex dynamics, and heat transfer problems.

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